MAYO AERO MEDICAL UNIT

STUDIES IN AVIATION MEDICINE

Volume II

Progress Reports: 1 to 17

Subcom. O_2 & Anoxia Repts.: 1 - 4

Special Reports to AAF:

A, B and 1 to 5.

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With the cooperation of the

United States Army Air Forces, Materiel Command, Wright Field

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MAYO AERO MEDICAL UNIT

STUDIES IN AVIATION MEDICINE

Carried out with the assistance of the

NATIONAL RESEARCH COUNCIL, DIVISION OF MEDICAL SCIENCES

acting for the

COMMITTEE ON MEDICAL RESEARCH
of the
OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

With the cooperation of the

UNITED STATES ARMY AIR FORCES, MATERIEL COMMAND, WRIGHT FIELD.

Responsible Investigators: Walter M. Boothby, E. J. Baldes and C. F. Code

aided by many associates.

In Six Volumes

VOLUME 2:
PROGRESS REPORTS, NOS. 1 to 17.
REPORTS TO SUBCOMMITTEE ON OXYGEN AND ANOXIA, NOS. 1 to 4.
SPECIAL REPORTS TO AAF MATERIAL COMMAND, NOS. A, B and 1 to 5.

Mayo Clinic and Mayo Foundation for
Medical Education and Research,
University of Minnesota

Rochester, Minnesota
1940 - 1945

COMMITTEE ON WAR MEDICINE, MAYO ASSOCIATES
representing the
MAYO CLINIC AND MAYO FOUNDATION FOR MEDICAL EDUCATION AND RESEARCH
Dr. D.C. Balfour, Dr. C.W. Mayo*, Dr. R.D. Mussey, Dr. A.R. Barnes and Mr. H.J. Harwick

STAFF OF THE MAYO AERO MEDICAL UNIT

Responsible Investigators

High Altitude Laboratory: Walter M. Boothby, Chairman. Member of the Subcommittee on Oxygen and Anoxia of the Committee on Aviation Medicine, National Research Council.

Acceleration Laboratory:** E.J. Baldes, Vice Chairman. Member of the Subcommittee on Acceleration of the Committee on Aviation Medicine, National Research Council.
C.F. Code, Secretary. Member of the Subcommittee on Decompression Sickness of the Committee on Aviation Medicine, National Research Council.

Investigators

Staff of the Mayo Clinic and Mayo Foundation: (Full time) E.J. Baldes, J.B. Bateman, W.M. Boothby, A.H. Bulbulian, C.F. Code, H.F. Helmholz, Jr., E.H. Lambert, W.R. Lovelace, II and E.H. Wood. (Part time) J.D. Akerman,*** J. Berkson, H.B. Burchell, P.L. Cusick, H.E. Essex, G.A. Hallenbeck, W.W. Heyerdale, H.C. Hinshaw, J. Piccard,*** M.H. Power, C. Sheard, J.H. Tillisch, M.N. Walsh and M.M.D. Williams.

Fellows of the Mayo Foundation: R. Bratt, B.P. Cunningham, W.H. Dearing, E.W. Erickson, N.E. Erickson, J.H. Flinn, J.K. Keeley, J. Pratt, F.J. Robinson, R.F. Rushmer, G.F. Schmidt, H.C. Shands, H.A. Smedal, A.R. Sweeney, A. Uihlein, R. Wilder, Jr., J. Wilson and K.G. Wilson.

Officer assigned by the Air Transport Command of the Army Air Forces: K.R. Bailey, pilot.

Officers assigned by Air Surgeon's Office: O.O. Benson, Jr., J.W. Brown, J.H. Bundy, D. Coats, E. Eagle, M.F. Green, J.R. Halbouty, R.B. Harding, J.P. Marbarger, M.M. Guest, O.C. Olson, C.M. Osborne, H. Parrack, N. Rakieten, J.A. Resch, H.A. Robinson, H.E. Savely, C.B. Taylor, L. Toth and J.W. Wilson.

Officers assigned by the Navy: W. Davidson and D.W. Gressley.

Officers sent by other governments: J.R. Delucchi, Argentina, and R.T. Prieto, Mexico.

Other investigators: M. Burcham, C.J. Clark, M.A. Crispin, R.E. Jones, G. Knowlton, H. Lamport, C.A. Lindbergh, C.A. Maaske, G.L. Maison, A. Reed and R.E. Sturm.

Technicians

High Altitude Laboratory: Henrietta Cranston, Lucille Cronin, Ruth Knutson, Eleanor Larson and Rita Schmelzer; Margaret Jackson (from Wright Field).

Acceleration Laboratory: L. Coffey, R. Engstrom, H. Haglund and A. Porter; Ruth Bingham, Velma Chapman, Marjorie Clark, Wanda Hampel and Marguerite Koelsch.

Secretaries

Evelyn Cassidy, Esther Fyrand, Marian Jenkins and Ethel Leitzen.

* Before going into military service.

** The major reports of the Acceleration Laboratory will be published shortly in the monograph entitled "The Effects of Acceleration and Their Amelioration," edited by the Subcommittee on Acceleration of the Committee on Aviation Medicine of the National Research Council.

*** From the Department of Aeronautical Engineering, University of Minnesota.

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Associates: H. F. Helmholz, Jr., J. B. Bateman, F. J. Robinson, E. H. Wood and E. H. Lambert.

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Associates: H. F. Helmholz, Jr., J. B. Bateman, E. H. Wood and E. H. Lambert.

No. 11, October 6, 1944. (A) Alveolar air study. (B) Decompression sickness. (C) Vest for aid in pressure breathing.
Associates: J. B. Bateman and H. F. Helmholz, Jr.

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Aeromedical Research Unit: [illegible], E. J. Baldes and C. F. Code.

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No. 7, July 27, 1943. (1) Sea level and 35000 foot level oxygen requirements. (2) Method of recording from subject on centrifuge. (3) Preliminary report on anti g suit.
Associates: H. F. Helmholz, Jr., F. J. Robinson and E. H. Wood.

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Associates: H. F. Helmholz, Jr., J. B. Bateman, E. H. Wood and E. H. Lambert.

No. 11, October 5, 1944. (A) Alveolar air study. (B) Decompression sickness. (C) Vest for aid in pressure breathing.
Associates: J. B. Bateman and H. F. Helmholz, Jr.

No. 12, December 8, 1944. High Altitude Laboratory: (1) Ballistocardiograph. (2) Roentgenkymograms. (3) Burns pneumatic balance resuscitator. Acceleration Laboratory: (1) G tolerance. (2) Valves and suits. (3) Test pilots. (4) Centripetal acceleration.
Associates: H. F. Helmholz, Jr., J. B. Bateman, E. H. Wood and E. H. Lambert.

No. 13, February 24, 1945. High Altitude Laboratory: (1) Comparison of sponge-rubber discs with single orifices for suitability as flow-meters. (2) Residual air. Acceleration Laboratory: (1) A-24 Douglas dive bomber tests. (2) Lamport pneumatic lever g suit. (3) G tolerance of women. (4) Minimum requirements of pressure in g suits. (5) Adjustable suit pressure. (6) Transverse acceleration.
Associates: H. F. Helmholz, Jr., J. B. Bateman, E. H. Wood and E. H. Lambert.

No. 14, April 20, 1945. High Altitude Laboratory: (1) Skin temperatures with pressure breathing. (2) Use of sponge rubber discs as resistance unit in gas flow meter. Acceleration Laboratory: (1) Comparison of results of g on pilot and passenger in airplane. (2), (3), (4) Testing efficiency of various suits and apparatus. (5) Effects of environmental temperature.
Associates: H. F. Helmholz, Jr., J. B. Bateman, E. H. Wood and E. H. Lambert.

No. 15, July 1, 1945. High Altitude Laboratory: (1) Analysis of factors involved in explosive decompression. (2) Residual air studies.
Associates: H. F. Helmholz, Jr. and J. B. Bateman.

No. 16, August 24, 1945. High Altitude Laboratory: (1) Residual air (technical procedures). (2) Oximeter readings at various altitudes replotted. (3) Translation of German confidential reports. Acceleration Laboratory: (1) Arterial blood pressure. (2) Crash stresses.
Associates: H. F. Helmholz, Jr., J. B. Bateman, E. H. Wood and E. H. Lambert.

No. 17, October 19, 1945. High Altitude Laboratory: (1) Lung emptying time. Acceleration Laboratory: (1) Cutaway suit. (2) Installation of equipment in SBD-6 plane for g studies.
Associates: H. F. Helmholz, Jr., J. B. Bateman, E. H. Wood and E. H. Lambert.

No. [illegible], [illegible] 1944. High altitude laboratory: (1) [illegible] [illegible] [illegible]. (2) [illegible] [illegible]. (3) [illegible] acclimatization laboratory: (1) [illegible] [illegible] [illegible]. (2) [illegible] [illegible].
Investigators: [illegible] [illegible] and [illegible].

No. [illegible], February [illegible], 1944. High altitude laboratory: (1) Comparison of [illegible] masks with single orifices for [illegible] on [illegible]-meters. (2) [illegible] air. Acclimatization laboratory: (1) A-[illegible] [illegible] [illegible]. (2) [illegible] [illegible]. (3) [illegible] of [illegible]. (4) [illegible] [illegible] of [illegible] and [illegible]. (5) [illegible] [illegible]. (6) [illegible] [illegible].
Investigators: [illegible], Jr., J. B. Bateman, E. H. Wood and [illegible].

No. [illegible], April [illegible], 1944. High altitude laboratory: (1) Skin temperature with [illegible] breathing. (2) Use of sponge rubber [illegible] as insulator unit in [illegible]. Acclimatization laboratory: (1) Comparison of results of [illegible] in [illegible]. (2), (3), (4) [illegible] efficiency of [illegible] apparatus. (5) Effects of environmental temperature.
Investigators: [illegible], Jr., J. B. Bateman, E. H. Wood and [illegible].

No. [illegible], [illegible] 1944. High altitude laboratory: (1) Analysis of factors involved in [illegible]. (2) [illegible].
Investigators: [illegible], Jr. and J. B. Bateman.

No. [illegible], [illegible], 1944. High altitude laboratory: (1) [illegible]. (2) [illegible] replicated. (3) [illegible]. Acclimatization laboratory: (1) [illegible]. (2) [illegible].
Investigators: [illegible], Jr., J. B. Bateman, E. H. Wood and [illegible].

No. [illegible], [illegible], 1944. High altitude laboratory: (1) [illegible]. Acclimatization laboratory: (1) Gateway suit. (2) [illegible] of equipment [illegible] for [illegible].
Investigators: [illegible], Jr., J. B. Bateman, E. H. Wood and [illegible].

Reports to Subcommittee on Oxygen and Anoxia, National Research Council.

No. 1, January 15, 1943. Reducing valves, regulators and economizer bags. Administration of oxygen to aviators.
By W. M. Boothby.

No. 2, April 20, 1943. Comparison of alveolar oxygen pressures, oximeter readings and percentage of saturation of hemoglobin.
By W. M. Boothby and F. J. Robinson.

No. 3, April 20, 1945. Summary of the development of positive pressure closed circuit jacket to be used in attempting to attain altitudes as high as 50,000 feet.
By W. M. Boothby.

No. 4, March 14, 1945. Summary of recent work on respiration.
By J. B. Bateman.

Reports to Army Air Forces Materiel Command, Wright Field.

Special Report A, November 1940. Accumulated nitrogen elimination at rest and at work.
By W. M. Boothby, W, R. Lovelace, II, and O. O. Benson.

Special Report B, December 30, 1940. X-ray photographs demonstrating air bubbles in wrist joint at 35,000 feet.
By W. M. Boothby, O. O. Benson and H. A. Smedal

Special Report No. 1, August 4, 1942. The advantages of both the demand and constant flow systems of oxygen administration are combined by the utilization of a small reservoir or economizer bag with the demand type mask.
By W. M. Boothby.

Special Report No. 2, August 4, 1942. Effects of toxic doses of digitalis and of prolonged deprivation of oxygen on the electrocardiogram, heart and brain.
By W. H. Dearing, A. R. Barnes, W. M. Boothby and H. E. Essex.

Special Report No. 3, August 20, 1942. Development of oxygen equipment: Physiological criteria to be considered by engineers.
By W. M. Boothby and E. J. Baldes.

Special Report No. 5. Indexed under C.A.M. Report No. 340.

Reports to [illegible]

No. 1, [illegible] 1941. [illegible]
[illegible]
By [illegible]

No. 2, April 29, 1942. Comparison of alveolar oxygen pressures, [illegible]
and [illegible] of [illegible].
By W. M. [illegible] and [illegible].

No. 3, April 20, 1942. Summary of the development of positive pressure closed
circuit [illegible] to be used in attempting to attain altitudes as high as
40,000 feet.
By W. M. [illegible]

No. 4, March [illegible], 1942. [illegible]
By [illegible]

Reports to Army Air Forces Materiel Command, Wright Field.

[illegible] November 1940. Accumulated nitrogen elimination at rest and at
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By W. M. Boothby, [illegible] and [illegible]

Special Report 3, December 30, 1940. X-ray photographs demonstrating air bubbles
in [illegible] joint at 35,000 feet.
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By W. M. Boothby and [illegible]

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COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

MONTHLY PROGRESS REPORT NO. 1

DATE May 14, 1942

NAME OF RESPONSIBLE INVESTIGATOR: Walter M. Boothby, M.D.

SUBJECT: Anoxia, Oxygen, Acceleration CONTRACT NO. OEMcmr-129

Up to the present time since receiving the contract we have been mainly engaged in building and equipping our new quarters. We hope to start moving on May 25th although we do not expect to have the installations completed until the middle of June. Attached herewith is a plan of our new building which I believe will be self-explanatory.

The particular point of interest is that Rooms No. 12 and 13 will be cold chambers and that a small low pressure chamber (13A) will be installed in Room 13 so that experiments can be done at low temperatures as well as at low pressures. The new large low pressure chamber, No. 10, has one unusual feature in that in the rear end there is a port-hole window looking into Room 9 which is completely blacked out. This permits Dr. Sheard and his associates to carry on easily studies on night vision etc., not only at ground level but with the subject at any desired elevation in the low pressure chamber.

Room 1 is Dr. Baldes' centrifuge which will probably be ready to turn experimentally within a few days although it will not be in complete running order with the carriage for another two weeks. The details in regard to any program that Dr. Baldes has will be reported directly by him.

The large laboratory marked No. 15 has been divided up into separate rooms as indicated and the executive offices and that of the secretary are in No. 17.

We expect to have a report ready to submit very shortly on "Oxygen Pressure in the Lungs at Various Altitudes." This report is essentially an indoctrination paper based on our experimental work here during the last three or four years. One of its main purposes is to explain in simple language how to calculate correctly the amount of oxygen needed at various altitudes to maintain normal or nearly normal alveolar oxygen concentrations. Much confusion has arisen on account of the fact that (1) the alveolar water vapor pressure in the lungs is always constant, (2) that the alveolar carbon dioxide pressure is constant up to an elevation of about 15,000 feet and then departs therefrom by hyperventilation in a very predictable manner unless anoxia is prevented by oxygen administration, (3) that in the steady state the number of molecules of nitrogen in the inspired air and in the expired air is the same regardless of changes in volume of the expired air from the inspired air and (4) that only oxygen and air of constant composition are mixed together from the outside to form a predictable mixture in the lungs after the addition of carbon dioxide and water vapor in well predictable quantities.

COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

MONTHLY PROGRESS REPORT NO. 2

DATE June 2, 1942

NAME OF RESPONSIBLE INVESTIGATOR: Walter M. Boothby, M. D.

SUBJECT: Anoxia, Oxygen, Acceleration CONTRACT NO. OEMcmr-129

Since our last report, we have been expecting to move into our new laboratory nearly every day. However, one thing after another has delayed the equipment and the builders asked us not to move in until next week.

Yesterday afternoon the York refrigeration apparatus arrived and the engineer has arrived with his workmen to start installing it, which will take about three weeks.

Our new low pressure chamber has been delayed because the Chicago Boiler Company could not get the frame forgings for the doors; delivery has been promised repeatedly at weekly intervals for the last six weeks. I hope the last promise of June 3 will be fulfilled. After the forgings are received they have to be machined and welded into the tank, and then the entire chamber must be shipped down. I am afraid this will not be ready for use until the first of July.

Dr. Baldes will report directly about his project.

Dr. Flexner is expected to arrive this afternoon so that he will be able to see for himself just how rapidly we are proceeding.

COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

MONTLY PROGRESS REPORT NO. 3

DATE July 4, 1942

NAME OF RESPONSIBLE INVESTIGATOR: Walter M. Boothby, M. D.

SUBJECT: Anoxia, Oxygen, Acceleration CONTRACT NO. OEMcmr-129

Unfortunately we have no new results to report from work done in the past month as we have been moving from our old quarters to our new ones. In fact, we will not have our chambers in working order for another ten days or two weeks so that no additional results will be available for some time yet. However, we are drawing up and will present in chart form some of our older results and as soon as these are completed will send them to you.

The meeting of the Subcommittee on Oxygen and Anoxia was very interesting and profitable. As pointed out by the Chairman, Dr. Bronk, the main purpose of the meeting was wisely directed to advising the new members of what was going on in the National Research Council Committees and how the Committees function.

My visit to the Jacksonville and Pensacola Air Stations arranged for me by Captain J. C. Adams, (MC) USN, Division of Aviation Medicine of the Bureau of Medicine and Surgery, was most profitable and will help us greatly in our work here at Rochester. As you know, Jacksonville is carrying out only indoctrinational work while Pensacola is also doing research work in conjunction with their School of Aviation Medicine. All the officers at both stations were most cooperative and did everything possible to make my visit enjoyable as well as profitable.

W.B.

COMMITTEE ON MEDICAL RESEARCH

of the

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MONTHLY PROGRESS REPORT NO. 5

DATE September 21, 1942

NAME OF RESPONSIBLE INVESTIGATORS: Walter M. Boothby, E. J. Baldes and C. F. Code

SUBJECT: Nitrogen Elimination and Venous Blood Nitrogen CONTRACT NO. OEMcmr-129

Boothby, Code and Associates: A new series of ten experiments (four subjects) on nitrogen elimination together with the simultaneous determination of the nitrogen content of the venous blood is reported. As the subjects varied in weight from 55 to 91 kg. the data as plotted has been transferred to a 70 kg. basis. The subjects, without breakfast, sat at rest in an easy chair in a comfortably warm laboratory; all the manipulation of valves, meters and vena puncture were carried out quietly by a trained team. The air in the lungs was washed out by 6 maximum exhalations and inhalations of pure oxygen (99.7%) without rebreathing so that the nitrogen content of the alveolar air was reduced from about 79 per cent to between 3 and 4 per cent. It could be assumed, therefore, that the nitrogen of the arterial blood as it leaves the lungs would be in approximate equilibrium with the nitrogen in the alveolar air and therefore contain between 0.05 and 0.10 volumes per cent nitrogen. The subject then breathed into a series of 5 bags containing about 4.7 liters of oxygen for periods of 5, 10, 15, 15 and 15 minutes. The nitrogen content of the bags at end of a period as determined by quadruplicate analysis carried out in specially designed Haldanes varied between 3.5 and 4.9 per cent. The volume of gas in the bags at end of each period was determined by a calibrated wet test meter and the nitrogen eliminated calculated. The nitrogen content of the anti-cubital venous blood was determined in duplicate on 5 cc. samples of whole blood read at 0.5 cc. on manometer apparatus using a technic developed for this purpose by Power from a combination of the Roughton and the Van Slyke and Neill methods.

The rate of nitrogen elimination was somewhat less than the "resting" rates previously reported by Behnke and by Boothby because in the present series of experiments the subject more closely approached the "basal state" than in the previous series and therefore had a slower circulation rate.

The rate at which the content of nitrogen in the venous blood decreased is essentially similar to that found by Ferris, Molle and Ryder (CAM Report No. 60).

The complete data are plotted in the accompanying chart which shows at a glance that there is at least some degree of inverse correlation between the two curves. However, the dissimilarity in the curvature of the two curves is extremely significant and probably indicates that the gaseous nitrogen in the intercellular and the intracellular spaces, relatively far removed from any patent capillaries, has not during the hour's duration of this experiment come anywhere near into equilibrium with the nitrogen in the blood of the capillaries. That is, there is still on the average a steep gradient from nitrogen pressure in the blood in the capillaries and the nitrogen pressure in the tissue spaces at a distance from the patent capillary.

Boothby: The new equipment for altitude studies is now completely installed. One large chamber holding ten persons with air conditioner and dehumidifier is available for ordinary temperature work. A medium sized chamber, holding three or four persons, has been placed inside a cold room that will go as low as 60° below zero Fahrenheit; it is available for studies involving extreme cold. Another small chamber for one individual or for animal work is also available. Low pressure chambers are equipped with all types of oxygen supply systems for testing any type of mask. A new magnetic type of microphone which can be attached to a specially designed communicating system is available for use in all types of oxygen masks. This communicating system developed by Waters Conley Company of Rochester works excellently at all altitudes up to 42,000 feet.

Baldes: The acceleration unit is now practically complete. Tests of the assembly have been made to date at 10 "G" with 400 lb. load in the swinging cock-pit. Operation seems satisfactory. There is no apparent vibration of the superstructure and starting and stopping can be accomplished easily in three seconds. At present the superstructure is being wired to provide A.C. channels, signal and recording circuits necessary for study of effects of "G" on man or beast. Also arrangements are being made so that a movie camera can be placed in the cock-pit so that colored films of the subject's reactions throughout the entire "G" cycle can be obtained.

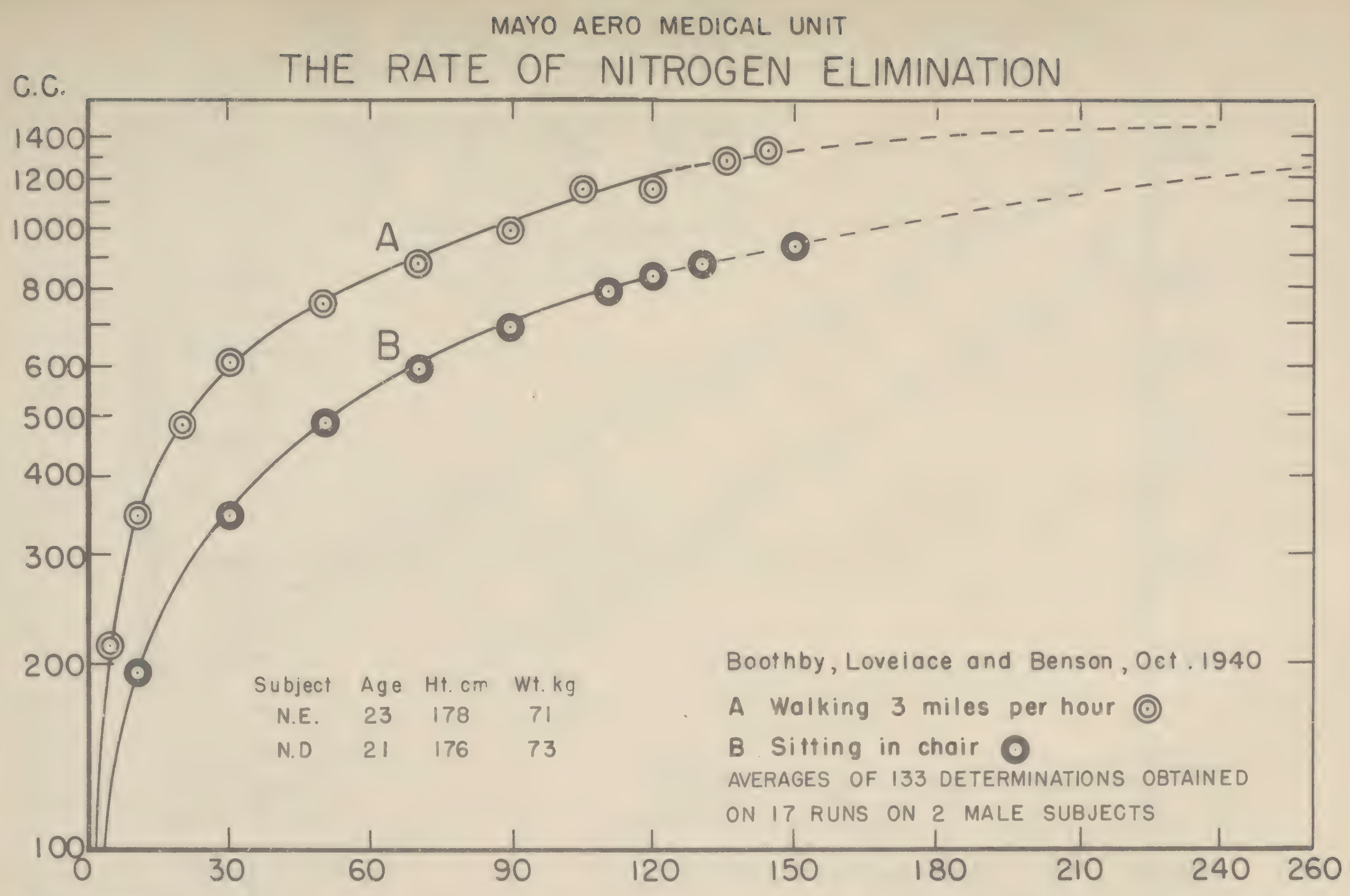


Chart VII-1

Data published in Physiology of Flight, page 27
Wright Field, 1940-1942

MAYO AERO MEDICAL UNIT

THE RATE OF NITROGEN ELIMINATION

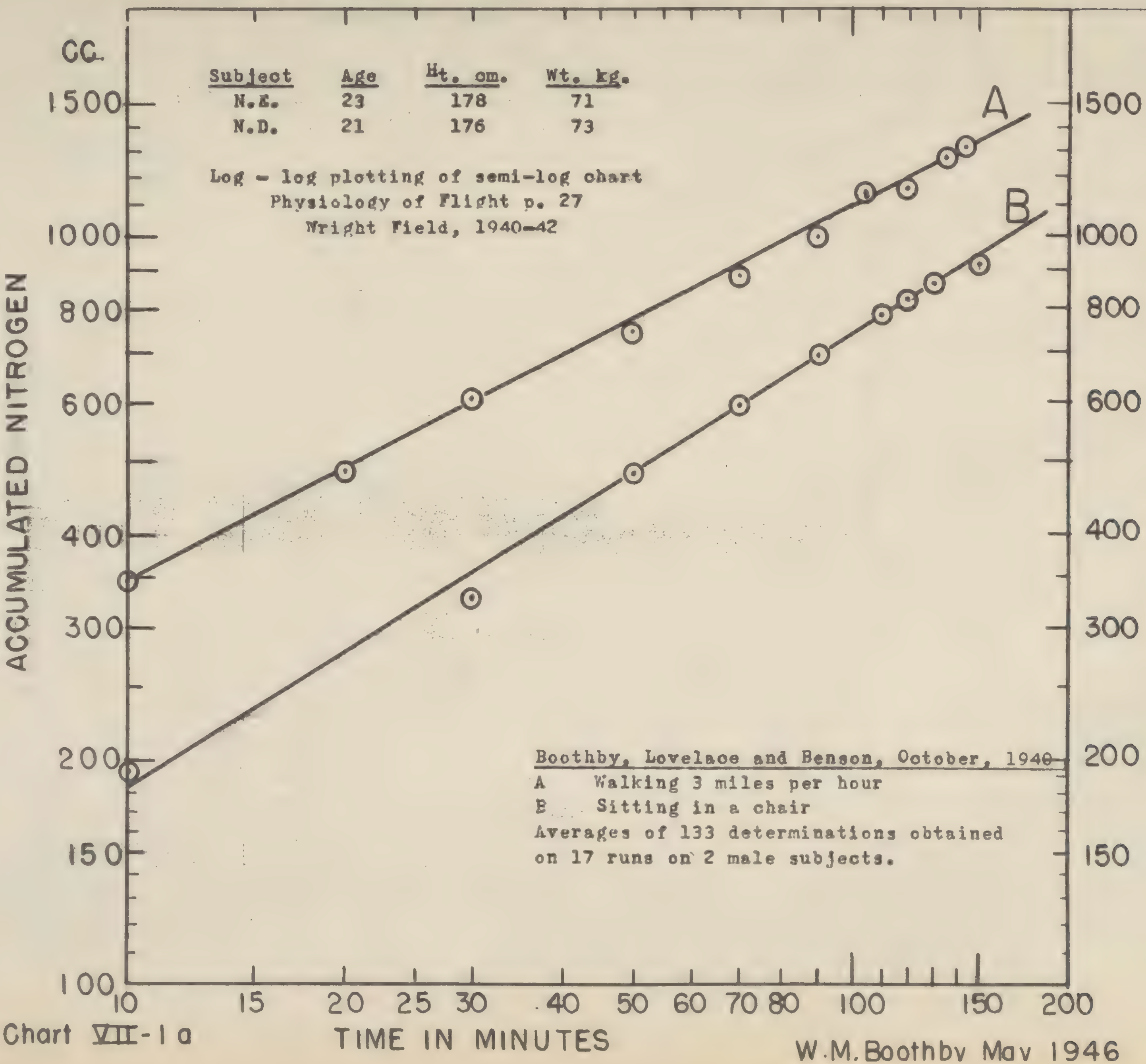
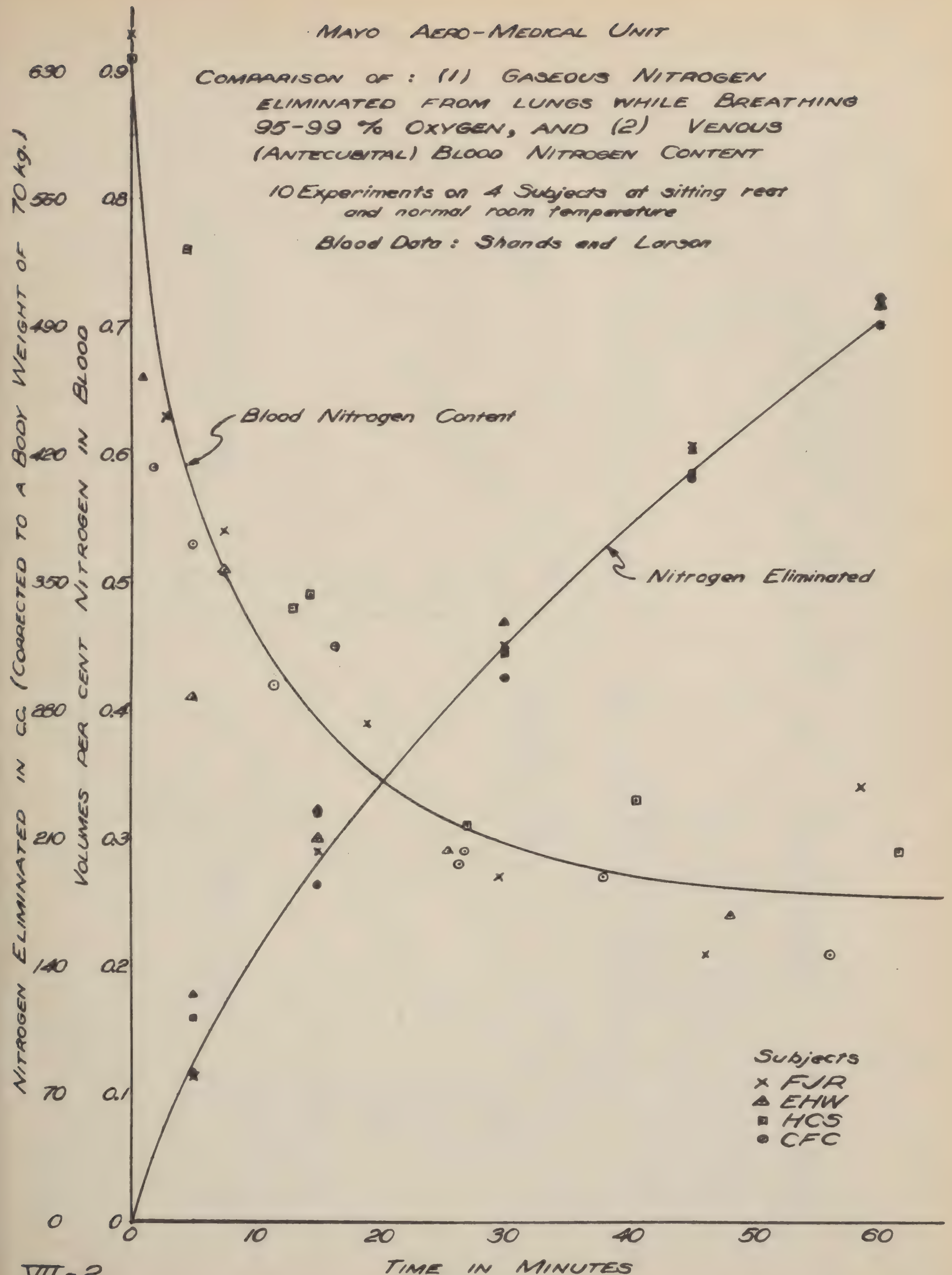
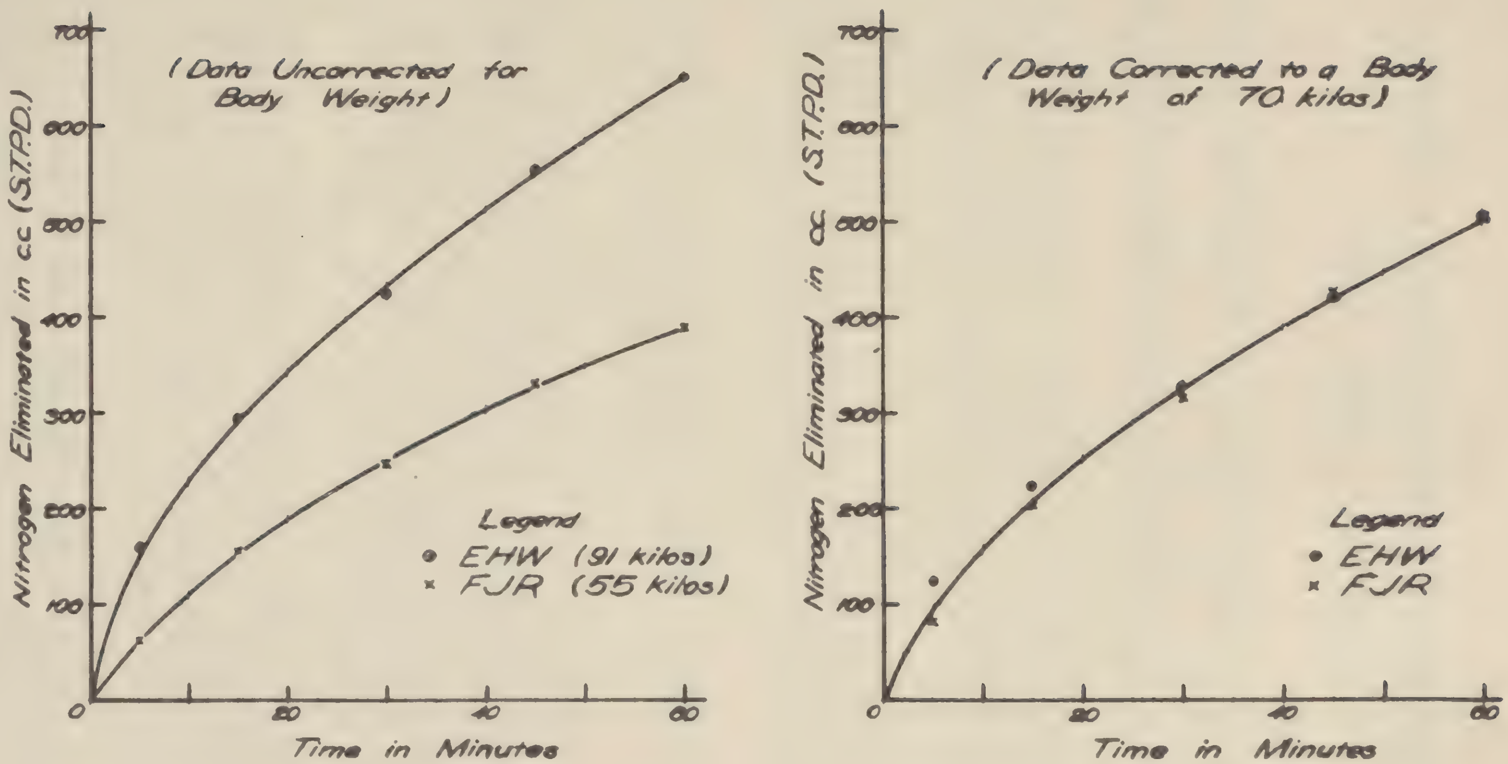


Chart VII-1a

W.M. Boothby May 1946


MAYO AERO-MEDICAL UNIT
COMPARISON OF : (1) GASEOUS NITROGEN ELIMINATED FROM LUNGS WHILE BREATHING 95-99 % OXYGEN, AND (2) VENOUS (ANTECUBITAL) BLOOD NITROGEN CONTENT
10 Experiments on 4 Subjects at sitting rest and normal room temperature
Blood Data : Shands and Larson
Blood Nitrogen Content
Nitrogen Eliminated
Subjects
× FJR
△ EHW
▫ HCS
• CFC
NITROGEN ELIMINATED IN CC. (CORRECTED TO A BODY WEIGHT OF 70 kg.)
VOLUMES PER CENT NITROGEN IN BLOOD
TIME IN MINUTES
0
70
140
210
280
350
420
490
560
630
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
10
20
30
40
50
60

VII-2



VII-3 COMPARISON OF NITROGEN ELIMINATED BY HEAVY AND LIGHT SUBJECTS

COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

MONTHLY PROGRESS REPORT NO. 6

DATE December 15, 1942

NAME OF RESPONSIBLE INVESTIGATORS: Walter M. Boothby, E. J. Baldes and C. F. Code

SUBJECT: Conservation of oxygen affected by the use of economizer bag in conjunction with demand regulator. CONTRACT NO. OEMcmr-129

A. I. Since our last report (No. 5, Sept. 21, 1942) we have been working on problems for the Army Air Forces Materiel Center under Contract No. W535ac-25829. The results of this work have been incorporated into reports 1, 2 and 3 of Series A. One copy of each is enclosed: additional copies are available.

II. The principle points in Report No. 1 of Series A can be summarized as follows:

1. The issue bail out equipment with a mouthpiece provides sufficient oxygen for a moderate amount of exercise for 30 seconds before bailing out at 35,000 feet without loss of consciousness in the descent.

2. It may, however, be inadequate to prevent unconsciousness accompanied by convulsions during an emergency parachute jump from 35,000 feet if more prolonged exertion is required prior to the jump.

3. In order for the aviator to have sufficient oxygen to maintain consciousness and exercise for 30 seconds at 40,000 feet a simple mouthpiece is inadequate because it does not conserve oxygen. Therefore it is necessary that the oxygen line from the jump bottle go into the demand type mask preferably provided with an economizer bag around the corrugated tube. In liew of a regular economizer bag the corrugated tube, if it has a volume of about 450 cc. will serve as economizer (as originally pointed out by Dautreband). The mask and corrugated tube must be held on firmly by appropriate attachments so that it will not be blown off while bailing out.

4. The aviator can only take between three and five full breaths at 40,000 feet without loss of consciousness. In other words, the aviator has only about 15 or 20 seconds leeway after interruption of his oxygen supply before unconsciousness develops. At an elevation between 40,000 and 42,000 feet the reserve amount of oxygen in the lungs is about one-half the normal amount at sea level or at 35,000 feet on pure oxygen.

5. There is a delay period at high altitudes of approximately 20 seconds after the oxygen mask has been replaced, after taking a few deep breaths of air before the maximum effect of anoxia produced by breathing air is felt. This delayed effect is due to the time required for the pure oxygen to enter the lungs, oxygenate the blood, and reach the brain. Therefore the aviator must realize that after breathing oxygen again, he will be worse before he is better.

III. The chief points in Report No. 2 of Series A include data in regard to frequency of aeroemphysema obtained on 21 crews containing 203 officers and men of the 307th Bombardment Group as follows:

44 crew flights were made	
23 men were incapacitated by bends	= 11% of individuals
20 flights were jeopardized by incapacitation of at least 1 crew member	= 46% of flights

IV. Report No. 3 of Series A demonstrates that an economizer bag on the corrugated tubing directly below the mask used in conjunction with a demand regulator conserves about 50% to 75% of oxygen whether or not the automix is on or off with the subject at sitting rest. The percentage saved would be less if the aviator were active although the absolute amount saved would be approximately the same. The utilization of an economizer bag does not effect the proportion of oxygen and air provided by the automix demand regulator.

B. For testing "g" tolerance the centrifuge is now equipped to record accurately the responses of the pilot to light and sound; changes in opacity of the ear using a green filter and four simultaneous recordings of EEG and (or) EKG. Preliminary testing of the x-ray equipment indicates that satisfactory results may be anticipated. Colored movies of the subject before, during and following a run are made possible by a motor driven camera the controls for which are manipulated by the observer. Preliminary tests of posture and certain anti-"g" devices are under investigation.

A number of glider pilots from the Rochester Glider Pilot School of the Army volunteered for a study of "g" tolerance and proved an excellent group with which to work. Each pilot was given an indoctrination course to familiarize him with the acceleration equipment; and when the tests were completed he was informed of his "g" tolerance. Usually the "g" at which blackout alone and blackout with unconsciousness occurred were determined in the upright position. The performance of the individual in the upright sitting position was then compared to that obtained when the seat was tilted to 30° with the horizontal. Tilting to this angle improved the performance. Attempts have been made to correlate the pre-test condition, the body measurements and the cardiovascular reactivity of the individual with resistance to "g".

Preliminary studies are in progress in which cardiovascular reactions during exposure to "g" are being estimated. Attempts are being made to correlate these findings with observations made when stress is applied to the cardiovascular system while stationary.

Studies are in progress in collaboration with David Clark in which the protection afforded by a simple type of pneumatic suit is being determined. A "g" valve that inflates the suit has been developed by Henry Wilder and its performance has been given some preliminary tests.

Ryan and Lindquist at the University of Minnesota have developed a tilting seat which shows promise of being an anti-"g" device worthy of serious consideration. As a result of tests carried out here and measurements obtained from Wright Field and aircraft manufacturers, they are modifying their seat so that it may be made to fit various types of aircraft.

COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

BI-MONTHLY PROGRESS REPORT NO. 7

DATE July 27, 1943

RESPONSIBLE INVESTIGATORS: Walter M. Boothby, M.D. and E. J. Baldes, Ph.D.

SUBJECT: Aviation Medicine CONTRACT NO. Symbol #M-2755
OEMcmr-129

1. Lately we have been investigating the oxygen requirements which engineers should strive to meet in the design and in the production of air-oxygen demand regulators. The problem centers mainly around the desirability of one of two "standards": Should it be recommended that (1) the partition of air-oxygen by the demand regulator be so planned that sea level conditions are maintained as closely as possible up to the critical point, or (2) is it proper for the physiologist to tell the engineer that if he maintains closely a 5,000 or 6,000-foot level the physiological requirements are met satisfactorily. More than 1,300 determinations of the alveolar CO_2 and O_2 pressures have been made, both at rest and at work, at all elevations up to 25,000 feet with the subject breathing air. The values for each observation as well as the mean values for each altitude have been plotted to show, not only the mean trend, but the individual variability.

No one method of calculating either the sea level or the 5,000-6,000 "standard" has yet been accepted generally. Although the various methods that have been used make no significant difference at low altitudes, there is material difference in the values obtained for high altitudes.

We hope to have the data and discussion ready very shortly to submit to the Subcommittee on Oxygen and Anoxia for their consideration.

Submitted by: Walter M. Boothby, M.D., H.F. Helmholz,Jr.,M.D., and
F. J. Robinson, M.D.

2. At present a series of continuous recordings are taken routinely on the centrifuge. These are the centrifuge r.p.m., the subject's respiration, electrocardiogram, ear opacity pulse and reaction time to auditory and visual signals. The ear opacity and ear pulse are recorded from two photovoltaic cell units placed over the pinna of the ear. A green Wratten filter No. 61 is placed in front of the ear opacity cell so that the amount of light transmitted to the cell is independent of the oxygen saturation of the blood per se. The output of this cell is recorded directly by means of an Einthoven galvanometer. The ear pulse cell is unfiltered. The output of this cell is coupled to an amplifier with time constants such that only the relatively high frequency ear opacity changes produced by blood pulsations from the heart beat are transmitted and amplified. The ear pulse is the most satisfactory objective measure available at present of an individual's tolerance to sudden exposure to high positive accelerations. All of the recordings mentioned above are taken simultaneously on a single camera so that synchronization of the different recordings is simplified. Specially constructed units containing a photoelectric cell and a preamplifier have been developed which will record finger opacity pulse and toe opacity pulse even during exposure to high acceleration. A battery of six Bourdon tube manometers fitted with mirrors to record on a camera has

been set up near the center of the centrifuge. Photographic records of the bladder pressures attained in pneumatic anti-g suits are taken with this camera in routine tests of this type of equipment. The finger pulse, toe pulse, and centrifuge r.p.m. are also recorded on this same camera. Comparative tests of the protective value of the F.F.S., the Navy suit, the Clark arterial pressure suit, and immersion in water have been made on a series of 12 subjects. Color movies have been taken of a typical series of exposures to acceleration required to assay the effectiveness of an anti-g device. Individual movies have been made which show the typical protection afforded by various anti-g devices and self-protective maneuvers. These movies show the face and shoulders of the subject, his reaction time to visual and auditory signals, the time in seconds, the acceleration, and the subject's ear opacity pulse.

A preliminary collaborative study of the protection afforded by a gradient pressure anti-g suit was carried out with Drs. H. Lamport and E. C. Hoff from the John B. Pierce Laboratory, Yale University School of Medicine. A total of one hundred and twelve exposures to acceleration were made on eight subjects. The procedure now adopted as a routine in this laboratory for the bio-assay of protective devices was followed in this study. The assay is carried out under reproducible conditions of minimal nervous and muscular tension. The accelerations at which vision is clear, dim, lost peripherally and lost completely and at which the ear pulse is lost serve as end points in the assay. The differences in the accelerations at which these changes occur with and without the protective devices give the protective value of the device in g units. Three different pressurizations of the gradient pressure suit were tested: (1) gradient pressures in the leg bladders, these pressures and the pressure in the abdominal bladder increasing with each increment of g, (2) the same as No. 1 except the abdominal bladder was inflated with a constant pressure of three to four pounds per square inch at all accelerations, and (3) single pressure in leg bladders which increased with acceleration and a constant pressure in the abdominal bladder of three to four pounds per square inch at all accelerations. Inflation of the suit to gradient pressures throughout (No. 1 arrangement) protected vision on the average 1.3 g; gradient pressures in legs and a constant pressure in abdomen (No. 2 arrangement) 1.3 g; and a single pressure in legs and a constant pressure in abdomen (No. 3 arrangement) 1.1 g. The protection given by inflation of the suit was seldom less than 1 g and sometimes as high as 2 g.

Summary

An outline is given of the routine recordings available for tests on the centrifuge at the Mayo Aero Medical Unit and progress of investigations under way indicated. Preliminary studies on protection afforded by anti-g devices have been extended to include the Navy gradient pressure suit, the F.F.S., the Clark arterial pressure suit, and immersion in water.

Submitted by: C.F. Code, M.D., E.H. Wood, M.D. and E.J. Baldes, Ph.D.

COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

BI-MONTHLY PROGRESS REPORT NO. 8

DATE January 17, 1944

RESPONSIBLE INVESTIGATORS: Walter M. Boothby, M. D. and E. J. Baldes, Ph.D.

SUBJECT: Aviation Medicine CONTRACT NO. Symbol # M-2755
OEMcmr-129

I. There are two reference points: (1) alveolar oxygen pressure and (2) tracheal oxygen pressure (inspired air at BTPS) which can be used in aviation work to (a) provide requirements for designing air-oxygen demand regulators; (b) allow for the physical effect of decreasing the nitrogen in the inspired air by increasing the proportion of oxygen (fO_2) supplied by the regulator; (c) compare the "effective" or physiologically equivalent altitude of an aviator at very high elevation (over 33,000 feet) breathing essentially pure oxygen, with an aviator at lower altitude (12 to 14,000 feet) breathing air; (d) compare the effect of acclimatization to elevation between sea-level and 10,000 feet on the ability of aviators to go to high altitudes; (e) study the completeness of equilibrium between alveolar oxygen pressure and the oxygen solution pressure in the blood; (f) study many other problems associated with respiration and circulation.

The contention of those working in this laboratory is to the effect that the tracheal oxygen pressure is the best point of reference because it is a fixed point (B-47). To use the alveolar oxygen pressure as calculated by the alveolar air equation as the point of reference involves the validity of the assumed factors inserted in the equation. It is probable that the physical effect of increasing the fO_2 is correctly (or nearly correctly) allowed for by the alveolar air formula if the alveolar CO_2 pressure and the R.Q. are maintained constant as in an assumed steady state. However, as yet the effect of the increased ventilation from anoxia, or from voluntary hyperventilation, or the effect of eating carbohydrates or fats on the physiologically compensating factors in the equation are as yet unknown. In fact not one of the methods of experimentally determing the alveolar values can at present be assumed to give true or exact mean values with certainty.

In a recent paper reviewing this discussion, J. B. Bateman has examined available experimental data in order to determine to what extent practical decisions are affected by the choice of one reference point or the other. He has concluded that as a rule it will make little difference which is used; in the case of the anoxic person it may, however, make a good deal of difference, but it is precisely in this case that the choice of experimental data to which the alveolar air equation can be applied becomes practically impossible.

Another section of the paper is devoted to a theoretical objection to the alveolar air equation. Early arguments are revived concerning the mechanism of gas exchange in the lungs, and it is contended that the presence of a stagnant cushion of "true" alveolar air of constant composition at the surface of the lungs would invalidate the equation.

SUMMARY OF MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

[illegible] PROGRESS REPORT NO. 9

DATE [illegible]

RESPONSIBLE INVESTIGATOR [illegible]

PROBLEM [illegible] CONTRACT [illegible]

1. Work on the following problems: (1) [illegible] oxygen pressure [illegible] and (2) [illegible]

The conclusion of those working in this laboratory [illegible]

In a recent paper [illegible]

[illegible]

II. Observations are now under way on Behnke's closed circuit apparatus and on the M.S.A. rebreather and confidential reports will be issued shortly.

Submitted by: Walter M. Boothby, H. F. Helmholz, Jr., J. B. Bateman and F. J. Robinson.

III. A study has been made of the protective value of the F.F.S. when this suit is inflated using air pressures of 1 pound per square inch at 1 g with an additional pound per g. An average protective value against the effects of positive acceleration of 2.2 g was obtained. In another study using water in the suit as recommended a protective value of approximately 1 g was obtained. An investigation of the protection against the effects of positive acceleration afforded by pulling on an airplane control stick has been made. It was found that heavy weights must be pulled before significant amounts of protection become evident. Nineteen pounds at 1 g and increasing by that amount per g was found to give up to 1 g protection. The protection afforded by different pressures applied by anti-g suits with different sized bladders to various areas of the body is being studied. A cardiotachometer permitting a continuous record of the pulse rate before, during and after acceleration has been developed and is now in routine use on the centrifuge. The instrument gives the pulse rate at each beat of the heart. A method by means of which the blood pressure may be recorded at intervals of less than five seconds is being developed for use on the centrifuge.

IV. Preliminary testing and some developmental work has been in progress on the Ryan-Lindquist g tensiometer which is designed to measure the opening shock of a parachute. A 200-pound dummy has been used in the drop testing here, while at Wright Field tests have been conducted using a dummy attached to a parachute and dropped from a plane. A newly designed instrument is now under construction which will record forces up to 50 g (10,000 pounds) for a period of 30 seconds on a foot of 16 mm. film. Final testing of the new model should be completed early in January.

Submitted by: C. F. Code, E. H. Wood, E. H. Lambert and E. J. Baldes.

COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

BI-MONTHLY PROGRESS REPORT NO. 9

DATE April 19, 1944

RESPONSIBLE INVESTIGATORS: Walter M. Boothby, M.D., E.J. Baldes, Ph.D., C.F. Code, M.D.

SUBJECT: Aviation Medicine CONTRACT NO. Symbol #M-2755
OEMcmr-129

1. Aero-embolism: In comparing the protective effects of prolonged inhalation of certain air-oxygen mixtures at altitude with those of short periods of pre-oxygenation at ground level, Dr. Bateman has found a six hour period breathing 40 per cent oxygen at 15,000 feet to be about equivalent to two hours breathing oxygen at ground.

2. Peripheral vascular changes accompanying pressure breathing: A series of measurements have been made by Drs. Sheard and Bateman of changes in skin temperature during pressure breathing both at ground and at simulated alttudes of 30,000 to 40,000 feet. The results are by no means consistent. A typical response seems to be a slight rise in skin temperature, although under suitable conditions it appears that an incipient peripheral vasoconstriction can be precipitated by breathing.

3. Visual adaptation: (Dr. Sheard) (a) Data obtained on several subjects show that the level of dark adaptation is improved (i.e. made comparable to or possibly equal to levels for cone and rod dark adaptation at ground levels) when pressure breathing is emploayed at altitudes of 35,000 to 42,000 feet. (b) A limited number of tests obtained thus far indicate that the metabolic rate and/or blood sugar level as influenced by food has a definite influence on dark adaptation. That is, the increased metabolism and adequate blood sugar as a result of food are favorable to superior night vision.

4. Alveolar airs in men and women: Chart with tabulated data (I-6e) compares the alveolar oxygen and carbon dioxide pressure of men and women obtained by the Haldane-Priestley method while breathing air and at sitting rest in low pressure chamber at simulated altitudes up to 20,000 feet. All subjects were acclimatized to a ground altitude of 1,000 feet; the "flights" were usually about two hours long and alveolar air samples were obtained usually during ascent and less often on descent after a rapid ascent. Ten minutes elapsed after reaching a given altitude before an alveolar air sample was obtained and at least five minutes elapsed between samples.

(a) The alveolar CO_2 pressure in females is usually 2 to 4 mm. lower than in males. (b) The alveolar O_2 pressure is very slightly (1 mm.) higher in females than in males.

5. Acceleration: C.F. Code, E.H. Wood, E.H. Lambert and E.J. Baldes.

A study has been completed of some of the factors concerned in the effectiveness of the standard anti-blackout suits. Partly as a result of this study a new anti-blackout suit has been developed in collaboration with the David Clark Company. This suit weighs less than 5 pounds and employs no rubber in its construction. Inflated with a single pressure of 1.0 p.s.i. per g, it affords between 1.5 and 2.0 g protection on the centrifuge. This suit and the regular G.P.S. have withstood 1,000 inflations to a pressure of 5 p.s.i. without breakdown.

Studies are under way on the value of self-protective maneuvers while wearing anti-blackout suits. The Valsalva maneuver increases protection obtained from a suit, but lowers the g tolerance of the unprotected individual. Pressure breathing (14 inches H_2O) increases protection obtained from a suit, but has no effect on the g tolerance of unprotected individuals. Pressure breathing increases comfort of the suit, while the effort necessary for pressure breathing is much less during g with and without a suit.

An x-ray study of the effect of high acceleration (up to 6 g) on the intervertebral disks has been completed. No measurable narrowing of the intervertebral spaces was found to occur. A method for taking repeated x-ray photographs of the chest synchronized with the heart cycle is being developed for use on the centrifuge. Preliminary tests have been made.

A method of recording systolic blood pressure indirectly at intervals of 2 to 5 seconds during positive acceleration has been developed to the point that routine determinations can be made. Preliminary studies (at 72° F.) have shown that the blood pressure at the level of the external auditory meatus falls on the average 28 mm. of Hg per g above 1 g in routine centrifuge runs. The lowest level is reached in 6 to 7 seconds after maximum g and is followed by partial recovery during maintenance of maximum acceleration.

Studies have been made of the reciprocal relation of blood pressure and intraocular pressure in the blackout. The acceleration at which blackout occurs is lowered by mild positive pressure applied to the eyeball pneumatically. Negative pressure applied to the eyeball prevents blackout which occurs without unconsciousness. High positive eyeball pressures cause blackout at 1 g similar in nature and latent period to blackout due to high acceleration. The studies give direct support to the view that blackout which occurs during consciousness is retinal in origin.

A small vertical centrifuge has just been completed at the Mayo Aero Medical Unit. An 18-foot plant rotates through its middle about a horizontal axis. One standard aircraft seat is attached to the plank near the center of rotation and a second seat may be moved out from the center to a distance of approximately 8½ feet The apparatus is so designed that it may be set in motion quickly by means of four extended springs capable of applying a force of approximately 3,000 pounds to a small iron wheel 44 inches in diameter. Rotation is then maintained manually. The radial acceleration amounts to approximately 1 g. Hence, a study may be made on the human of the effects of 1 g centrifugal force combined with gravitational force as a seated subject is rotated in a vertical plane. The equipment may be useful in studying vestibular effects as a function of the distance from the center of rotation in the vertical plane.

A meeting of the Subcommittee on Acceleration was held in this laboratory on February 23 and 24.

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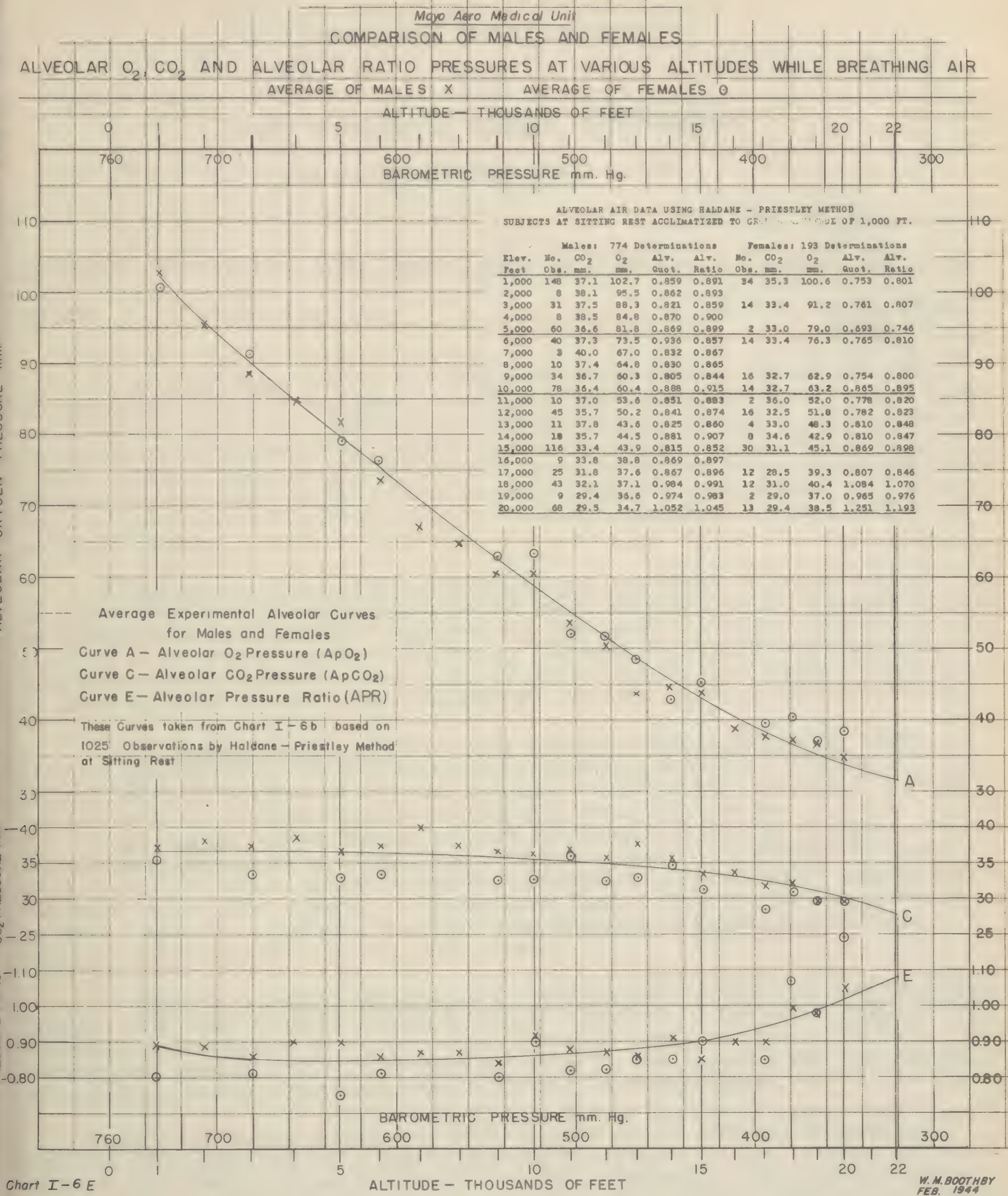

ALVEOLAR AIR DATA USING HALDANE - PRIESTLEY METHOD
SUBJECTS AT SITTING REST ACCLIMATIZED TO GR[illegible]UDE OF 1,000 FT.

	Males: 774 Determinations					Females: 193 Determinations				
Elev. Feet	No. Obs.	CO_2 mm.	O_2 mm.	Alv. Quot.	Alv. Ratio	No. Obs.	CO_2 mm.	O_2 mm.	Alv. Quot.	Alv. Ratio
1,000	148	37.1	102.7	0.859	0.891	34	35.3	100.6	0.753	0.801
2,000	8	38.1	95.5	0.862	0.893					
3,000	31	37.5	88.3	0.821	0.859	14	33.4	91.2	0.761	0.807
4,000	8	38.5	84.8	0.870	0.900					
5,000	60	36.6	81.8	0.869	0.899	2	33.0	79.0	0.693	0.746
6,000	40	37.3	73.5	0.936	0.857	14	33.4	76.3	0.765	0.810
7,000	3	40.0	67.0	0.832	0.867					
8,000	10	37.4	64.8	0.830	0.865					
9,000	34	36.7	60.3	0.805	0.844	16	32.7	62.9	0.754	0.800
10,000	78	36.4	60.4	0.888	0.915	14	32.7	63.2	0.865	0.895
11,000	10	37.0	53.6	0.851	0.883	2	36.0	52.0	0.778	0.820
12,000	45	35.7	50.2	0.841	0.874	16	32.5	51.8	0.782	0.823
13,000	11	37.8	43.6	0.825	0.860	4	33.0	48.3	0.810	0.848
14,000	18	35.7	44.5	0.881	0.907	8	34.6	42.9	0.810	0.847
15,000	116	33.4	43.9	0.815	0.852	30	31.1	45.1	0.869	0.898
16,000	9	33.8	38.8	0.869	0.897					
17,000	25	31.8	37.6	0.867	0.896	12	28.5	39.3	0.807	0.846
18,000	43	32.1	37.1	0.984	0.991	12	31.0	40.4	1.084	1.070
19,000	9	29.4	36.8	0.974	0.983	2	29.0	37.0	0.965	0.976
20,000	68	29.5	34.7	1.052	1.045	13	29.4	38.5	1.251	1.193

Chart I–6 E

COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

BI-MONTHLY PROGRESS REPORT NO. 10

DATE June 1, 1944

RESPONSIBLE INVESTIGATORS: W. M. Boothby, M.D., E. J. Baldes, Ph.D., C. F. Code, M.D.

SUBJECT: Aviation Medicine CONTRACT NO. Symbol #M-2755
OEMcmr-129

1. Aero-embolism: Further data have been obtained by Dr. Bateman concerning the protective effect of prolonged inhalation of certain air-oxygen mixtures at ground level and at 15,000 feet. In addition to their practical bearing on the question of the incidence of aero-embolism in airplane crews ascending to high altitudes at the end of prolonged flight at 15,000 to 20,000 feet, the data provide evidence concerning the relative importance of the primary factor (nitrogen) and of subsidiary factors (such as local carbon dioxide production) in causing symptoms. A report will be presented shortly.

2. Hyperventilation and pressure breathing: In a series of experiments by Dr. Bateman the rate of recovery of alveolar carbon dioxide from the decrease produced by pressure breathing has been contrasted with the rates of recovery from true hyperventilation of various degrees of intensity. Recovery from pressure breathing is much more rapid than recovery from hyperventilation and the data suggest that a fall in alveolar carbon dioxide is not necessarily a reliable index of hyperventilation.

3. Sea level alveolar carbon dioxide and oxygen partial pressures: Data obtained by Helmholz at the High Altitude Laboratory of Consolidated Vultee Aircraft Corporation. 217 analyses of alveolar air on 16 subjects, male and female, working and living in San Diego (within 100 feet of sea level) indicate that at sea level the average alveolar oxygen partial pressure is 108 mm. and average alveolar carbon dioxide partial pressure is 37 mm. The technic used was in all respects the same as that used in collecting data previously presented from the Mayo Aero Medical Unit. The oxygen value falls directly on extrapolated line of the curve already presented in Chart I-6b. This is higher than previously reported by Haldane and others and which are often assumed to be sea level values.

4. Comparison between low altitudes breathing air and high altitudes breathing oxygen: This study is based on over 1,400 determinations of the alveolar air by the Haldane-Priestley method on subjects acclimatized to ground level of 1,000 feet. The average data obtained up to 22,000 feet breathing air are compared with the average data obtained at high altitudes above 35,000 feet breathing oxygen.

Aviator breathing oxygen at high altitudes: As the inspired tracheal air contains only oxygen and water vapor any decrease in volume of the alveolar air cannot decrease the alveolar oxygen pressure. The APR is always 1.0. The alveolar oxygen pressure can be determined directly by subtracting the alveolar carbon dioxide pressure from the tracheal oxygen pressure.

Aviator breathing air at low altitudes: As the inspired tracheal air contains nitrogen in addition to oxygen and water vapor any decrease or increase in volume of the alveolar air increases or decreases the pressure of nitrogen because there is no net change in the number of nitrogen molecules. Therefore when there is a decrease in volume (example, with an APR of 0.9) there is less available oxygen and, therefore, a decrease in the alveolar oxygen pressure. Thus both the alveolar carbon dioxide and the increase in nitrogen pressure must be subtracted from the tracheal oxygen to obtain the alveolar oxygen pressure. This effect of nitrogen in lowering the aviator's oxygen pressure when breathing air as compared with high altitudes breathing oxygen is emphasized and a new method of graphically illustrating this fact is presented. A complete report will be available shortly.*

5. Acceleration: C.F. Code, E.H. Wood, E.H. Lambert and E.J. Baldes.
During the past few months work in the Acceleration Laboratory has been chiefly concerned with: (1) determining the factors involved in the anti-blackout protection afforded by the pneumatic suits, (2) assisting in the development of a simplified effective and practical anti-blackout suit. It has been found that pressure applied to the abdomen is the most important single factor in the anti-blackout protection afforded by pneumatic devices. Pressure applied to the legs alone affords little protection, while pressurization of the legs during application of pressure to the abdomen multiplies the protection supplied by the abdomen alone by a factor in the neighborhood of two. Considerable progress has been made in simplifying existing models of anti-blackout suits. A suit built by Mr. David Clark of Worcester, Massachusetts which does not involve which does not involve the use of rubber bladders has proven the simplest, most efficient and most practical of those so far tested.

It has been found that the output of the B-3 Romec instrument pump when connected with a suction relief valve and the necessary g valves is reduced at altitudes above 20,000 feet to a degree which might impair the protection afforded by pneumatic suits inflated by this pump. Tests on the new Cornelius diaphragm pump powered by a 24 volt DC motor indicate excellent performance at high altitudes and sufficient output to pressurize pneumatic anti-blackout suits.

* This relationship can be expressed most easily by the following equation:

$$\text{Alv. } pO_2 = \text{Trach. } pO_2 - \left[\text{Alv. } pCO_2 + (\text{Alv. } pN_2 - \text{Trach. } pN_2)\right]$$

$$\text{or } pO'' = pO' - \left[pC'' + (pN'' - pN')\right] \quad \text{where}$$

one prime ' = tracheal air and two primes " = alveolar air.

MAYO AERO MEDICAL UNIT

COMPARISON BETWEEN LOW ALTITUDES BREATHING AIR AND HIGH ALTITUDES BREATHING OXYGEN

based on over 1400 determinations of the alveolar air by the Haldane – Priestley method on subjects acclimatized to ground level of 1000 feet

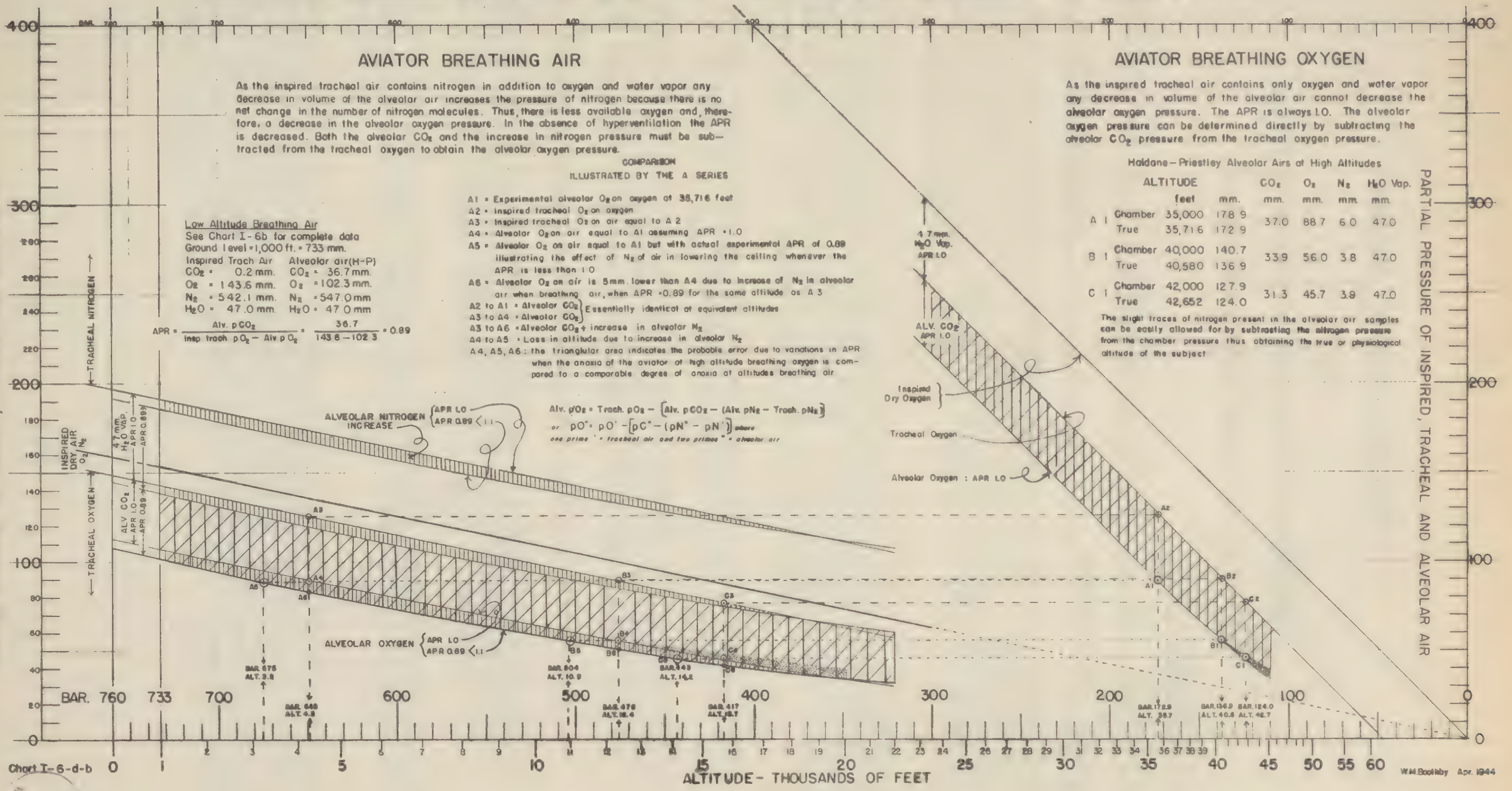

Chart I-6-d-b

W.M. Boothby Apr. 1944

COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

BI-MONTHLY PROGRESS REPORT NO. 11

DATE October 6, 1944

RESPONSIBLE INVESTIGATORS: W. M. Boothby, M.D., E. J. Baldes, Ph.D., C. F. Code, M.D.

SUBJECT: Aviation Medicine CONTRACT NO. OEMcmr-129

A Studies have been continued by Boothby, Helmholz and Bateman on the physiology of respiration with especial references to changes that occur at high altitudes and the advantages obtained by various types of pressure breathing. The following reports have been completed and sent in to the Committee on Aviation Medicine for publication as interim reports:

1. Alveolar respiratory quotients: An experimental study of the difference between true and alveolar respiratory quotients, with a discussion of the assumptions involved in the calculation of alveolar respiratory quotients and a brief review of experimental evidence to these assumptions. June 14, 1944. Report No. 341. By J. B. Bateman and Walter M. Boothby.

2. The effects of altitude anoxia on the respiratory processes. August 1944. By H. F. Helmholz, Jr., J. B. Bateman and Walter M. Boothby.

3. The reduction of alveolar carbon dioxide pressure during pressure breathing and its relation to hyperventilation, together with a new method of representing the effects of hyperventilation. September 1944. By J. B. Bateman.

B In addition the following study on Decompression Sickness has been made:

4. Susceptibility to Decompression Sickness: The effects of prolonged inhalation of certain nitrogen-oxygen mixtures compared with those of exposure to pure oxygen. September 1944. By J. B. Bateman.

These studies are being continued and considerable attention is being devoted to the physiologic and theoretic problems involved as well as to the practical phases pertinent to aviation.

C The laboratory type of vest for counter pressure originally designed (2-43) and tested physiologically for use at very high altitudes by Lt. C. B. Taylor, M.C., and Lt. J. P. Marbarger, A.C., while assigned to the Mayo Aero Medical Unit for temporary duty by the Air Surgeon's Office, has been redesigned to meet the practical needs of aviators as well as make it suitable for production. Several vests have been made available for field tests.

COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

BI-MONTHLY PROGRESS REPORT NO. 12

DATE December 8, 1944

RESPONSIBLE INVESTIGATORS: W. M. Boothby, M.D., E. J. Baldes, Ph.D., C. F. Code, M.D.

SUBJECT: Aviation Medicine CONTRACT NO. OEMcmr-129

High Altitude Laboratory - W. M. Boothby, J. B. Bateman and H. F. Helmholz, Jr.

1. Dr. Bateman has completed the calibration of the ballistocardiograph and records have been obtained on a considerable number of normal subjects under various conditions. A report will be presented in due course.

2. Dr. Helmholz and I have completed a movie obtained from roentgenkymograms which illustrate the cardiac action under normal and positive pressure breathing. The movie also shows very distinctly the respiratory cycle of the subject breathing normally in the upright position and also lying on his left side; the most striking feature is the rhythmic movement of the heart with each respiratory cycle and the fact that this movement appears much greater with the subject lying on his side than when upright. There is an undulating appearance in the motion of the diaphragm. The diaphragm is definitely lowered and the thoracic cavity expanded with positive pressure breathing and the movement of the heart with the respiratory cycle is restricted.

3. Major Olson of Wright Field brought for study the Burns Pneumatic Balance Resuscitator. Studies made here by him showed that although the apparent respiratory volume was increased 50 to 75 per cent, yet the amount of CO_2 washed out was negligible. The apparatus, which fits into a mask like the Linde positive pressure valve, will probably prove a very valuable clinical aid.

Acceleration Laboratory - E. H. Wood, E. H. Lambert, E. J. Baldes, C. F. Code.

1. G tolerance and protection afforded by pneumatic devices when tested in the centrifuge and in the A-24 Douglas dive bomber are being compared. The results to date show small but interesting differences between the centrifuge and the airplane.

2. Improvements in valves and suits currently in use in the Army and Navy are being developed and tested.

3. Test pilots contemplating exposures to high accelerations in jet propelled aircraft have been tested and indoctrinated to methods of protection on the centrifuge.

4. Upon the suggestion of Colonel W. R. Lovelace, II, tests of a man's ability to move about when exposed to centripetal acceleration have been carried out. These experiments were conducted in order to obtain some exact information as to the g under which a man might still be able to escape from a spinning aircraft. Somewhat sur-

prising results were obtained. Accelerations as low as 0.5 g significantly impeded escape activities, and accelerations between 1 and 2 g greatly hampered all types of movement involving the entire body. Between 3 and 4 g it became impossible for most subjects to move the body at right angles to the direction of the force. A parachute could not be donned above 3 g. It became impossible to successfully raise oneself from a seat, crawl, climb with or without the assistance of a ladder or rope against more than 2 to 3 g. A motion picture has been prepared illustrating these findings.

5. Dr. E. J. Baldes, who has been on temporary assignment to the U.S. Army Air Forces, has returned from the Southwest Pacific.

COMMITTEE ON MEDICAL RESEARCH

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BI-MONTHLY PROGRESS REPORT NO. 13

DATE February 24, 1945

RESPONSIBLE INVESTIGATORS: W. M. Boothby, M.D., E. J. Baldes, Ph.D., C. F. Code, M.D.

SUBJECT: Aviation Medicine CONTRACT NO. OEMcmr-129

High Altitude Laboratory - W. M. Boothby, H. F. Helmholz, Jr. and J. B. Bateman

1. Dr. Boothby and Dr. Helmholz have compared the properties of the sponge rubber disks used in the constant flow oxygen equipment with those of single orifices offering approximately the same resistance to flow. The pressure differences across the disk or orifice, as the case may be, for different rates of gas flow have been measured under various conditions. An orifice ¼" in diameter has the same resistance as two standard sponge rubber disks at an oxygen flow of approximately 8 l./min. (ambient) at ground (1,000 feet) and to a flow of 16 l./min. at 28,000 feet. In the case of the orifices with lower rates of flow the resistance decreases rapidly to zero pressure at rates of flow of 2 to 4 l./min. With the sponge rubber disks the resistance decreases linearly to zero at zero flow. Therefore, the sponge rubber disks are to be preferred as a means of retaining oxygen in the mask system especially during the expiratory pause. At high rates of gas flow, especially during expiration at work, the sponge rubber disks are also preferable because the increase in pressure is nearly linear with increasing flow (ambient) and reaches only 1.3 cm. water pressure at 40 l./min., while with the single ¼" orifice the pressure increases very rapidly, reaching 6.0 cm. water at 40 l./min. Mixtures of helium and oxygen gave, with sponge rubber disks, the same linear increase in pressure with increase in ambient flow. These observations confirm those of Boothby, Lovelace and Benson made in 1940 on the advantages and possibilities of porous disks of different sizes and thickness. The results also suggest that sponge rubber disks would form suitable resistance elements for a gas flow meter.

2. Dr. Bateman's program is directed toward an estimate of the importance of unequal pulmonary ventilation and of respiratory variations in blood flow in normal persons, and the quantitative bearing of such effects upon the measurement of:

(a) the composition of "average" alveolar air
(b) the residual air
(c) the respiratory dead space
(d) the diffusion constant of the lung
(e) the rate of nitrogen elimination during inhalation of oxygen.

To this end, estimates of residual air by two independent methods have been made and are being continued; the composition of alveolar air in resting and working subjects during expiration at different rates has been measured; and ballistocardiographic studies are continuing.

Acceleration Laboratory - E. J. Baldes, C. F. Code, E. H. Wood and E. H. Lambert

1. The protection afforded by the Navy coverall (Navy Type Z, Army Type G-4) anti-blackout suit which contains the simplified bladder system developed in this laboratory was tested in the A-24 Douglas dive bomber assigned to this laboratory by U.S. Army Air Forces, Wright Field. In the same subjects the protection afforded in the airplane was compared with that obtained during tests on the centrifuge. There was no significant difference in the protective value of the equipment when tested by these two methods. The average protection afforded by the suit was 1.1 g when inflated to 1 p.s.i. per g from 1.5 g (standard Navy C-C-1 valve) and was 1.4 g when inflated to 1 p.s.i. per g (Army G-2 valve).

2. In collaboration with Dr. Harold Lamport, Yale University School of Medicine, New Haven, Connecticut, a model of the Lamport pneumatic lever anti-blackout suit as constructed by General Electric Company was tested on the centrifuge. Tests were made on ten subjects. Pressures of 2 p.s.i. and 3 p.s.i. per g were used. The protection afforded vision and the protection against loss of blood from the ear was: for 2 p.s.i. per g - 1.0 and 1.2 g; and for 3 p.s.i. per g - 1.2 and 1.4 g, respectively. The electrically controlled inflation valve developed by Mr. R. J. Sertl of General Electric was also tested. Lace adjustments utilized by Mrs. Helen J. Lester of General Electric on the suit were found to have advantages over the more conventional types of lace adjustment.

3. Experiments designed to determine the g tolerance of a series of women have been undertaken.

4. The testing and the development of pressure sources for the inflation of anti-blackout suits has continued. Opinion in the laboratory has crystallized sufficiently to allow the statement that to meet minimum requirements of present needs a pressure source must be capable of: (1) generating a pressure of 4 p.s.i., and (2) maintaining an output of 3 liters of ambient air per second against an output resistance of 4 p.s.i. To fulfill optimum requirements of present needs the pressure source should be capable of: (1) generating a pressure of 15 p.s.i., and (2) maintaining an output of 6-10 liters of ambient air per second against a resistance of 4 p.s.i.

5. An adjustable suit pressure control valve has been developed. This mechanical device allows the easy adjustment by the pilot of the pressure (ratio of suit pressure to g) to which his anti-blackout suit is inflated. The pilot on the ground or in level flight can set the valve to any one of four possible pressure settings. The attachment also provides an off position and a manual control which allows the pilot to pressurize his suit in level flight. The attachment fits on to a standard Navy Type C-C-1 (Army M-1, Cornelius suit-tank) valve replacing the standard g weight and valve cap. Use of this type of valve will allow each pilot to increase or decrease the comfort and the protection afforded by his "as issued" anti-blackout suit so that his g tolerance will correspond to the squadron average.

6. A preliminary study has been made of the ability of a series of five subjects to withstand high transverse accelerations while in the sitting position. The tests allowed the following conclusions: (a) The subjects in the sitting position were able to withstand transverse accelerations up to 10 g for periods of 3 to 10 seconds. (b) Distracting pain in the epigastrium occurred in two subjects. This was decreased by supporting the hips and houlders above the level of the cockput floor. (c) The pulse rate decreased and the blood content of the ear increased during transverse acceleration experienced in the sitting position. Premature systoles occurred during some exposures in two subjects. (d) No harmful effects were observed from exposure to transverse accelerations up to 10 g for 3 to 10 seconds in the sitting position. (e) Comparing the difference in sensation between exposures to 8, 9 and 10 g, all subjects felt that they would be able to withstand 12 g for 2 to 3 seconds.

[illegible] ... E. ... Burton, G. F. ... C. L. ... [illegible]

1. The ... [illegible] ... (Army Type ..., Army Type ...) ... [illegible] ... developed in this laboratory was tested ... [illegible] ... in the ... [illegible] ... There was no significant difference in ... [illegible] ... The average ... [illegible] ... and was ... [illegible] ... Army ... values.

2. In collaboration with Dr. ... [illegible] ..., Yale ... School of Medicine, New Haven, Connecticut, ... [illegible] ... was tested ... [illegible] ... of 2 ... per ... [illegible] ... loss of blood from the ... [illegible] ... The ... [illegible] ... controlling ... [illegible] ... by ... [illegible] ... were found to have ... [illegible]

3. Experiments designed to ... [illegible] ... of women have been ... [illegible].

1. The ... [illegible] ... and the development of ... [illegible] ... in the laboratory was ... [illegible] ... (1) ... [illegible] ... (2) ... [illegible] ... (3) ... [illegible] ... of 1 ... [illegible]

... [illegible] ... (2) ... [illegible] ... of 1 ... [illegible]

2. An ... [illegible] ... pressure ... valve has been developed. This ... [illegible] ... of the pressure ... of ... [illegible] ... the valve to ... [illegible] ... The ... [illegible] ... valve ... [illegible] ... One of this type of valve ... [illegible]

3. ... [illegible] ... of a series of ... [illegible] ... conclusions: (a) The ... [illegible] ... up to ... [illegible] ... of 3 to ... [illegible]

COMMITTEE ON MEDICAL RESEARCH

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BI-MONTHLY PROGRESS REPORT NO. 14

DATE April 20, 1945

RESPONSIBLE INVESTIGATORS: W. M. Boothby, M.D., E. J. Baldes, Ph.D., C. F. Code, M.D.

SUBJECT: Aviation Medicine CONTRACT NO. OEMcmr-129

High Altitude Laboratory - W. M. Boothby, H. F. Helmholz, Jr. and J. B. Bateman

1. The final report on the effects of pressure breathing for skin temperature of the extremities is being prepared and will be forwarded shortly.

2. The possible use of the sponge rubber disk as a resistance unit in gas flow meters is being investigated. Preliminary experiments indicate that possibly the standard sponge rubber disk will need to be modified before it can be so used. Work continues on the ballistocardiograph. A method for critical damping of the table is felt to be a necessary next step. Estimates of residual air have brought out discrepancies in methods available. Further studies are being made.

Acceleration Laboratory - E. J. Baldes, C. F. Code, E. H. Wood and E. H. Lambert

1. Studies on the physiologic effects of positive acceleration being conducted in an A-24 Douglas dive bomber assigned to this laboratory by U. S. Army Air Forces, Wright Field, have been extended to pilots pulling their own g in flight. Determinations of the pilot's g tolerance and the anti-blackout protection afforded to pilots by the G-3 suit (inflated to 1 p.s.i. per g from 1.5 g) were made using twelve instructur pilots at Randolph Field. Preliminary examination of the data obtained indicates that the average tolerance is about 0.7 g higher when the man is piloting the airplane than when he is passively acting as a subject in the airplane. The protection afforded the pilot by the G-3 suit is approximately the same as that afforded a subject on the human centrifuge.

2. The performance of the adjustable suit pressure control valve attachment for the C-C-1 valve has been tested in the FM-2 ("Wildcat") airplane by the Ryan Aeronautical Company. Valve performance was satisfactory. Pilots experienced in g suit protection preferred the two higher pressure settings provided by the valve (1.3 and 1.5 p.s.i. per g starting from 1.5 and 1.3 g respectively). The standard Navy C-C-1 valve is set to deliver 1.0 p.s.i. per g starting from 1.8 g.

3. At the suggestion of Lt. Comdr. H. A. Schroeder the Ryan Aeronautical Company in collaboration with the Mayo Aero Medical Unit has completed extensive tests of the inflation systems for anti-blackout suits in the FM-2 airplane. The findings in the airplane confirmed in all respects the results obtained with simulated airplane assemblies at simulated altitudes in the chamber of the Mayo Aero Medical Unit. The use of an oil separator with a 1/8" diameter oil outlet restriction reduced the effective output of the assembly about 10,000 feet below that obtained when an oil outlet restriction of 1/16" diameter (B-12 oil separator) was

used. The performance of the plane assembly was found to fall below minimum adequate requirements for g suit inflation at altitudes above 15,000 to 20,000 feet when the B-2 or B-11 type instrument pump was used. This minimum adequate performance ceiling was increased about 10,000 feet when the larger type B-3 or B-12 instrument pump was used.

4. The protection afforded by a suit with a restricted (more comfortable) abdominal bladder (Berger G-3) is being compared with the protection afforded by a suit with a nonrestricted (less comfortable) abdominal bladder (Clark G-3). When inflated to equal pressures the Clark G-3 suit affords more protection than the Berger G-3 suit. However, the Berger abdominal bladder causes less subjective distraction than does the nonrestricted Clark bladder. On the centrifuge, due to the added protection afforded, subjects prefer the Clark G-3 to the Berger G-3 suit. These experiments are the preliminary step in a program directed towards developing an abdominal bladder which will afford increased g protection without a concomitant increase in subjective discomfort.

5. The effects of changes in environmental temperature and humidity on g tolerance have been studied in fifteen subjects. Sudden exposures of one hour or more to hot humid atmospheres lowers g tolerance. No study has been made of the possible effects of acclimatization.

COMMITTEE ON MEDICAL RESEARCH
of the
OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

BI-MONTHLY PROGRESS REPORT NO. 15

Date July 3, 1945

NAME OF RESPONSIBLE INVESTIGATOR W. M. Boothby, M.D., E. J. Baldes, Ph.D. and C. F. Code, M.D.

SUBJECT Aviation Medicine CONTRACT NO. OEMcmr-129

High Altitude Laboratory - W. M. Boothby, H. F. Helmholz, Jr. and J. B. Bateman.

I. Dr. Helmholz has attempted a new analysis of the factors involved in explosive decompression, in the belief that recent pressure cabin design calls for a more exact definition of zones of safety, and of possibel danger zones, in explosive decompression. The relative areas over which sudden decompression can occur are greater than hitherto.

In previous work the expansion of lung gases has been assumed to take place according to the equation:

$$\text{Expansion} = \frac{P + p - (pW'')}{P - (pW'')}$$

the corresponding expression for adiabatic expansion being

$$(\text{Expansion})^{1.4} = \frac{P + p - (pW'')}{P - (pW'')} \quad \text{approximately.}$$

There are, however, other possibilities: if expansion is so rapid that the water vapor in the lungs is not replaced to any significant extent, then $(\text{Expansion})^{1.4} = \frac{P + p}{P}$

If, on the other hand, there is sufficient time for both water vapor and carbon dioxide to be replaced as soon as they are removed by expansion, then

$$(\text{Expansion})^{1.4} = \frac{P + p - (pC'') - (pW'')}{P - (\bar{p}C') - (pW'')}$$

and there will be an analogous equation if this is also true for oxygen. In these equations P is atmospheric pressure (ambient), p is cabin pressure differential, (pW'') is alveolar water vapor pressure, (pC'') is alveolar CO_2 partial pressure before decompression, $(\bar{p}C')$ is venous CO_2 pressure, assumed to be the extreme alveolar partial pressure established after decompression.

It is important to determine the relative importance of these several equations for different times of decompression. Two additional factors should be considered: 1. At what rates of flow of gas through the larynx and, possibly, other parts of the respiratory passages, does turbulence become an important factor in causing development of excessive relative intrapulmonary pressures? 2. To what extent is the phase of the respiratory cycle at the instant of decompression a factor in determining the physiological effects of explosion? Drury, Greely and others have shown the importance of this factor in the injury of rats by explosive decompression. Some of the variables involved in such an effect are (i) initial direction of air flow (ii) inertia and elasticity of chest wall as influenced by the respiratory cycle (iii) patency of the respiratory passages.

It would seem that further experimental work on the problem is indicated.

II. Dr. Bateman is continuing a study of the residual air of a small number of normal persons, using a modified open circuit method. Emphasis is being placed upon the errors introduced by nitrogen elimination, the effects of this factor being studied chiefly (a) by varying the number of breaths of pure oxygen taken and (b) by altering the state of activity of the subject. The results suggest that uncontrolled variations in circulation rate are more important than any other single source of error in measurement of residual air by this method.

COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

BI-MONTHLY PROGRESS REPORT NO. 16

DATE August 24, 1945

RESPONSIBLE INVESTIGATORS: Walter M. Boothby, M.D., E. J. Baldes, Ph.D., C. F. Code, M.D.

SUBJECT: Aviation Medicine CONTRACT NO. OEMcmr-129

High Altitude Laboratory - W. M. Boothby, H. F. Helmholz, Jr., and J. B. Bateman

1. Work is continuing on the measurement of residual air and on other procedures which are expected to be of value in the differentiation of the various causes of respiratory and circulatory insufficiency. The ballistocardiograph table is being equipped with a damping system and the mechanical properties of hydron bellows are being studied in connection with the use of such bellows as part of the recording system of the table.

2. The data of Boothby and Robinson (CAM Report No. 163, June 1943) on the oxygen saturation of the blood of persons breathing air at various simulated altitudes (oximeter readings) have been replotted in Figure 1 in order to give a more direct representation than that in the original paper. This was done at the informal request of Lt. D. E. Goldman of the Naval Medical Research Institute, who is assembling data of this kind for statistical study.

3. Considerable attention has been directed recently, at the request of Col. W. R. Lovelace and Dr. E. J. Baldes, to recent German confidential literature on catapult seat ejection as a method of rescue from high speed aircraft. A number of these papers have been translated and turned over to Wright Field.

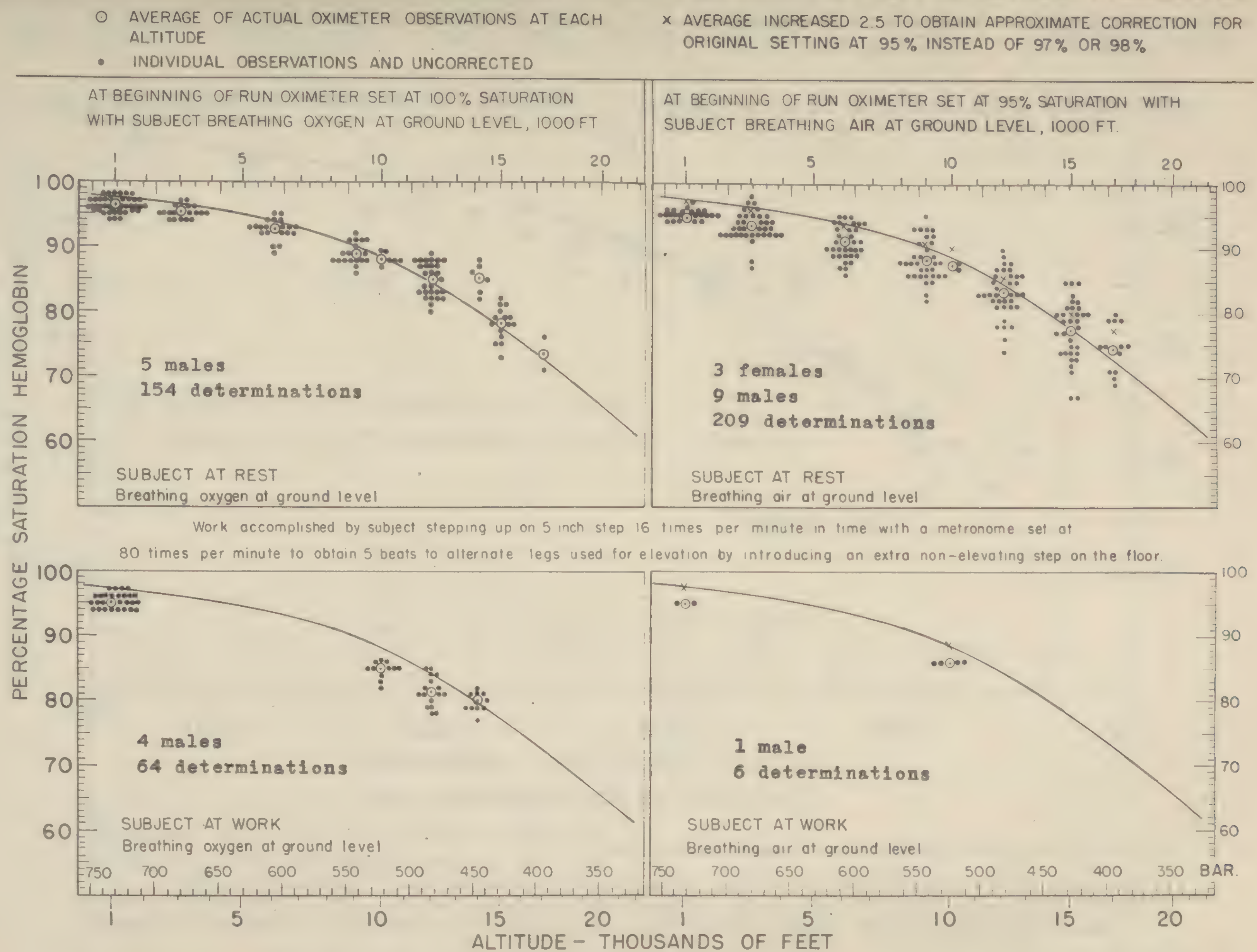
Acceleration Laboratory - E. J. Baldes, C. F. Code, E. H. Wood and E. H. Lambert

1. Studies of the changes in arterial blood pressure in man during exposure to acceleration on the centrifuge have continued. Arterial blood pressure (both diastolic and systolic) obtained by arterial puncture has been recorded continuously during g by a Hamilton manometer and by an electrical strain gauge manometer. Studies of the blood pressure changes during standard and protected runs have been made on seven subjects. The correlation of the blood pressure changes at head and at heart level with visual symptoms and other physiologic changes are being studied. Preliminary analysis indicates that the changes in systolic pressure are similar to those obtained by the indirect blood pressure technique reported in CAM Report No. 338.

2. A preliminary investigation has been made of methods suitable for the recording of the high stresses involved in experimental deceleration (crash).

[illegible]

PERCENT SATURATION HEMOGLOBIN PLOTTED AGAINST BAROMETRIC PRESSURE

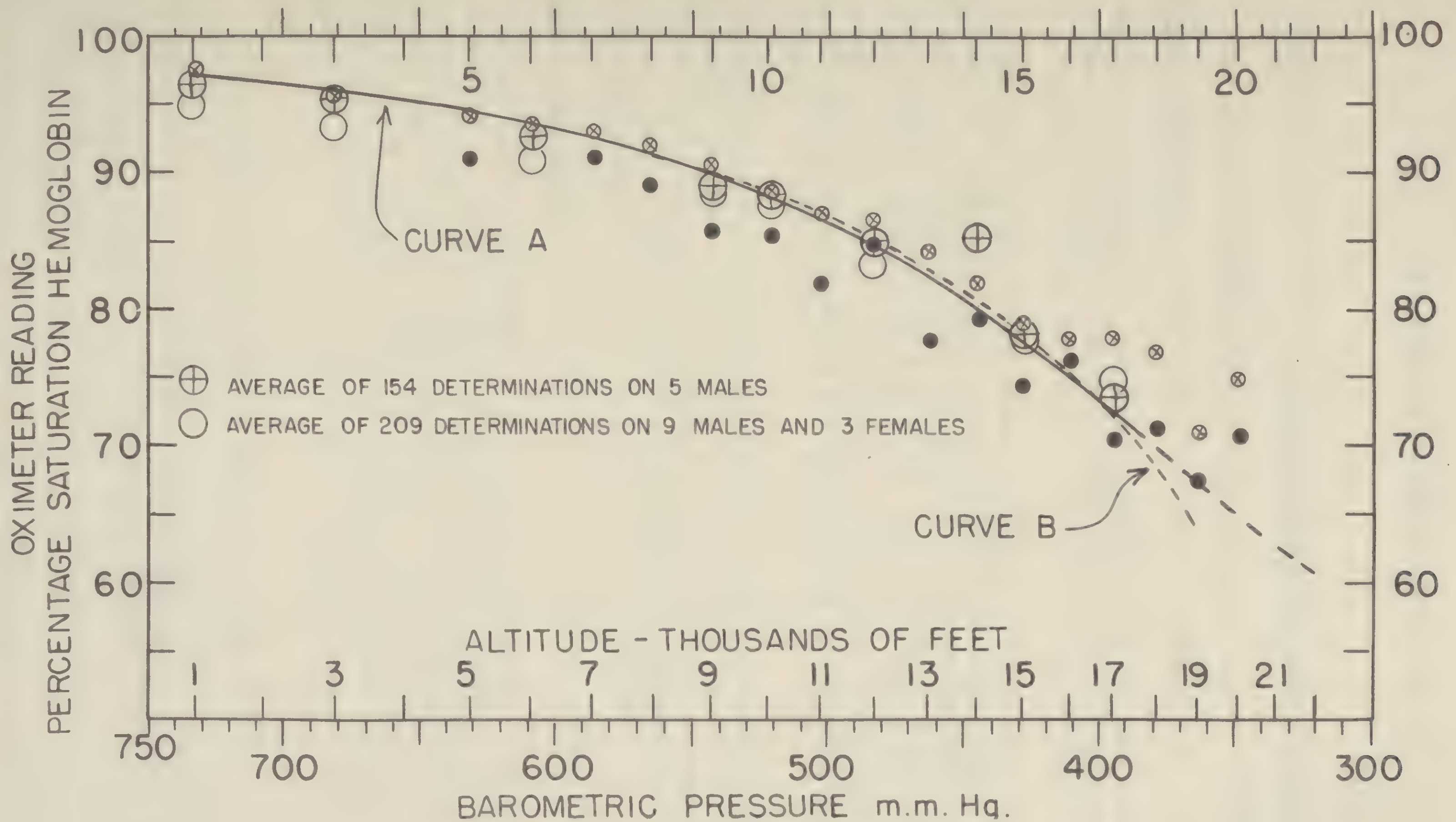


Smoothed curves obtained by reading; First the average alveolar oxygen pressure read from smooth curve A on chart I-6b, *Mayo Aero Medical Unit* (same as chart A-I in *Handbook of Respiration on Data in Aviation* prepared by Subcommittee on Oxygen and Anoxia of CAM for CMR, OSRD.) Second the corresponding percent saturation Hemoglobin read from Dills Oxygen Dissociation Curve, pH 7.4

(Fig. 9 Physiology of Flight 1940–1942, Wright Field, AAF.)

CHART III-10H Replotting data of Boothby and Robinson, CAM Report No. 163, June 1943 W.M. Boothby, July 1945

AVERAGE PERCENT SATURATION HEMOGLOBIN - OXIMETER



Data from the Mayo Aero Medical Unit - 1943

⊕ Oximeter set at 100% - Subject breathing oxygen
○ Oximeter set at 95% - Subject breathing air
} Not over 10 minutes at progressively increasing altitudes

Curve A: Obtained by reading: First the average alveolar oxygen pressure read from smooth curve A, chart A-1, Handbook of Respiration, Subcommittee on Oxygen and Anoxia N.R.C. Second the corresponding percent saturation hemoglobin from Dill's dissociation curve, pH 7.4, Fig. 9 Physiology of Flight 1940-1942, Wright Field, AAF.

Data from the Naval Medical Research Institute, Bethesda

⊗ Less than 10 minutes at progressively increasing altitudes
● More than 15 minutes at progressively increasing altituds (not over 30 minutes)

Curve B: chart B-4 in Handbook of Respiratory Data in Aviation, Subcommittee on Oxygen and Anoxia, N.R.C.

Chart III-10k

W. M. Boothby, April, 1946

COMMITTEE ON MEDICAL RESEARCH
of the
OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

BI-MONTHLY PROGRESS REPORT NO. 17

Date 19 October 1945

NAME OF RESPONSIBLE INVESTIGATORS Walter M. Boothby, E. J. Baldes and C. F. Code

SUBJECT Aviation Medicine CONTRACT NO. OEMcmr-129

High Altitude Laboratory - W. M. Boothby, H. F. Helmholz, Jr. and J. B. Bateman.

Study of residual air and lung emptying time is being continued. A new spirometer has been disigned for use in connection with a new experimental procedure intended to reduce the time required for the residual air measurements.

Normal persons and others with pulmonary lesions whose residual air is measured are also being subjected to a series of exercise tests intended to give some indication of the character and degree of the impairment responsible for dyspnea and related symptoms of pulmonary and circulatory failure. These tests are based upon those already in use by Cournand but the final form appropriate to routine study of the effects of altitude anoxia has not yet been decided upon. A feature of the tests as carried out here is the continuous recording of pulse rate by means of the Waters Conley cardiotachometer.

Equipment is being installed for the direct recording of movements of the ballistocardiograph table using a microprojector. The indirect method involving a water-filled sylphon bellows and glass spoon gage has proved to be untrustworthy in our hands, but the study of this method will be resumed when reliable records of table movement are available for purposes of comparison.

Acceleration Laboratory - E. J. Baldes, C. F. Code, E. H. Wood and E. H. Lambert.

The protection afforded by the Navy Z-3 (cutaway suit) has been determined on the centrifuge. In one series of assays on 10 subjects the suit was worn over the Navy electrically heated flying suit. In a second series of assays the suit was worn over the standard flying coverall. Two pressure settings (1.0 p.s.i./g from 1.5 g and 1.5 p.s.i./g from 1.4 g) were used in each of the series of assays. The average and the extremes of the protection afforded (visual symptoms and ear opacity) by the Z-3 suit under these conditions are given in the following table.

Average protection afforded by the Navy (cutaway) suit

Type of suit	No. of subj.	Standard C-C-1 valve	High setting adjustable C-C-1 valve
Z-3 over Navy electrically heated suit	10	(0.3-1.0) 0.6	(0.6-1.6) 0.9
Z-3 over standard clothing	10	(0.3-1.2) 0.7	(0.8-1.3) 1.0
Z-2 (G-4) coverall suit	18	(0.7-1.5) 1.1	(1.1-2.4) 1.4

The equipment installed in the A-24 dive bomber used in the study of the physiology of exposure to acceleration in the airplane is being dismantled. A later model of this plane, SBD-6, is being equipped with a newly developed portable recording unit. This unit will weigh about 20 pounds and be about 4½ x 6 x 18 inches external dimensions. It will record simultaneously on 3½-inch width photographic paper: acceleration, altitude, airspeed, suit pressure, ear pulse, ear opacity and time. Respiration and the response to peripheral and central light signals can also be recorded.

A two-pressure adjustable attachment for the C-C-1 valve which is reliable, simple to operate and to manufacture, has been perfected by the David Clark Company. Two pressures (1.0 p.s.i./g from 1.8 g and 1.4 p.s.i./g from 1.5 g) and a manual operation button are provided. The performance of the valve on the centrifuge has been satisfactory. Tests of its performance in the plane are currently in progress.

Studies of direct arterial blood pressure in the radial artery are being continued. Decreases in blood pressure at heart level during unprotected exposures to accelerations up to the unconscious level are surprisingly small. The blood pressure regularly rises to hypertensive levels at heart level during the period of compensation which usually occurs after about 5-seconds exposure to the sustained acceleration.

Inflation of an anti-blackout suit produces an increase in blood pressure at heart level. This increased blood pressure is well sustained during the entire period (15 seconds) of suit inflation. When inflated to equal pressures the more effective type suits produce greater increases in blood pressure at 1 g and at increased accelerations up to 8 g. Preliminary measurements indicate that the protection afforded by a suit can be explained on the basis of the increase in blood pressure which inflation of the suit produces. Coupling the Valsalva manuever with inflation enhances the hypertensive effect produced by suit inflation. Execution of the M-1 self-protective maneuver produces a sustained hypertension at heart level both at 1 g and during 15-second exposures to increased acceleration.

No. I. Report to the Subcommittee on Oxygen and Anoxia, National Research Council

on

Reducing Valves, Regulators and Economizer Bags
Administration of Oxygen to Aviators

by

Walter M. Boothby, M. D.
Member of Subcommittee on Oxygen and Anoxia
National Research Council

The experimental work reported was done by
1st Lt. C. B. Taylor, M.C. and 2nd Lt. J. P. Marbarger, A.C.,
Liaison Officers from the Air Surgeon's Office
in cooperation with
Dr. F. J. Robinson, Dr. K. G. Wilson and Dr. B. P. Cunningham
Mayo Aero Medical Unit

January 15, 1943

The week which the Subcommittee on Oxygen and Anoxia spent in Washington learning the desires of the Army and Navy and hearing about the production difficulties from the various manufacturers was exceedingly profitable, at least to me. However, statements in regard to apparatus need verification and it was my intention to test out immediately in our laboratory as many of the points brought up as possible.

Unfortunately a febrile period which eventually developed into pneumonia slowed down and curtailed our investigations. However, during the last two weeks while convalescing at home a considerable number of tests have been run by my associates and I am taking the liberty of bringing this data (which I am sorry to say is not complete) and my own conclusions thereon to the attention of the Subcommittee for such action as it may deem fit.

My physician has insisted that I go to Arizona for a few weeks to recuperate. After that I intend to be able to go out to La Jolla to see Doctor MacKay.

The Pioneer Constant Flow Regulator. The constant flow type of regulator still used in large numbers by the Army Air Force is the Pioneer, known as the A-6, A-8 and A-9 series. While the A-6 was originally intended for use with the pipe-stem, some are still out and directions call for setting them when used with a mask at the twenty thousand mark. The A-6 and A-8 series can be used on either high or low pressure tanks; the A-9 series with rates of flow similar to the A-8 series can only be used on low pressure tanks carrying a maximum pressure of 400 pounds per square inch.

Descriptions of these and other regulators are given in the excellent new publication "Physiology of Flight" from the Aero Medical Research Laboratory, Wright Field. The rates of flow taken from this publication for the recent models of the A-8 and A-9 series are summarized in Table I.

The discrepancy in the specifications of the different models is great and because they cannot be distinguished at a glance considerable difficulty has arisen. Furthermore, all manufacturers have noted difficulty under field conditions (or even in the stock room, see last column of Table I) in maintaining a specified flow at various altitudes when relying upon a Bourdon tube pressure gage to indicate the amount of oxygen that will pass through a calibrated orifice. For that reason we have advised that a pressure gage working against a supposedly constant orifice is not a reliable flow indicator; a kinetic type of flow meter is far safer. In any case, we strongly recommend that flow meters be double calibrated for inactive and active aviator. The inactive flow can be used in non-combat areas whenever it is necessary to conserve oxygen for a long flight; frequently it is very important for all aviators to be able to use the minimum amount of oxygen that will supply their needs at sitting rest as opposed to moderate exercise.

Freezing of Constant Flow System. Rather frequent reports have been made that the constant flow system is likely to freeze. It is not, of course, the system that is at fault; the bad results have been due to specific faults in individual units of the system and these can be and in part have been remedied. If the oxygen used is not dry the regulator may freeze. More frequently it has been the fault of the mask due to the fact that the A-8A or A-8B mask was not designed for use in extreme cold. One difficulty is that the opening into the economizer bag is at the most dependent part of the mask so all water that condenses in the mask runs into the connector and bag where it freezes. For this reason all recently designed masks have no opening or valve at the most dependent part. Another difficulty is that the diameter of the bakelite connector between the mask and economizer bag, while ample for breathing under ordinary conditions, may quickly fill up with ice in extremely cold weather. Moreover, in the early models there was no protective covering over the turrets containing the sponge rubber discs to prevent the wind from blowing on them and thus keep them from freezing.

Since it is technically impossible from the production standpoint to increase the diameter of the bakelite connector or to change its position, most of the difficulty has been remedied by increasing the length of the connector so that it projects into the mask about one-third to one-half inch and thus prevents the condensed moisture from running into the connector, freezing and blocking it. Now, as in other masks, the water will drain out between mask and chin, making it advisable to lift up the mask very slightly at frequent intervals to let the water run out.

Coverings are now being supplied to protect the sponge rubber discs from the direct blast of the wind so that these do not freeze under the standard test conditions.

Present Pioneer and Aro Standard Reducing Valve Combined with Air-Oxygen Demand Regulator. At the present time there are available and in production two types of air-oxygen demand regulators designed on entirely different principles for diluting with air the oxygen from the supply tank at elevations below 30,000 feet. Both of these regulators have the reducing valve enclosed in the same casing with the air-oxygen regulator.

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The Bendix activates its dilutor (automix) by the injector principle regulated by an aneroid; this type delivers a slightly too rich mixture at low altitudes but requires few moving parts. Oxygen coming from the so-called emergency valve is prevented from leaking out through the air-intake port by an appropriate valve.

The Aro is designed on the principle of an air-port and oxygen-port where the air-port is gradually closed and the oxygen-port gradually opened by an aneroid as the aviator ascends. This method of air-oxygen partition requires several moving parts as well as a very careful adjustment of intake pressure of both oxygen and air. As now constructed there is no valve which prevents the oxygen from the emergency valve leaking out through the air-intake port of the dilutor when the dilutor (automix) is on at moderate altitudes; this is dangerous because in general it is unknown to aviators and in consequence they may not get oxygen when needed by simply turning on the so-called emergency valve.

The negative pressure required to open the valve of the present model of the Bendix is significantly less than that required by the present model of the Aro when the subject is exercising, especially at the lower levels. Service reports now probably available at Wright Field should present evidence to indicate which of the two types stands up best to field conditions.

The manufacturers of both the Pioneer and the Aro designs have up to very recently had difficulty in obtaining correct air-oxygen mixtures due frequently to "creeping" of the aneroid and other mechanical difficulties. These difficulties are now largely overcome by more careful inspection. However, it must be remembered that a slightly "lean mixture", one on the low borderline, can become dangerous if in addition there is a slight inboard leak around the mask; the method of decreasing this danger will be discussed.

Pioneer Intermittent Positive Pressure Demand Regulator. One method of reducing the danger inherent in a demand type regulator is that suggested by the Pioneer Instrument Company (Bendix). They have recently added to the standard negative pressure demand regulator an attachment which permits instant change into an intermittent positive pressure demand regulator that will open against a positive pressure of 0.1" (0.25 cm.) and will not shut off until the positive pressure reaches a 0.2" (0.5 cm.) of water; the positive pressure is referred to as "intermittent" because on inhalation a very definite negative pressure develops.

In the curves of the pressure inside the mask, while using this intermittent positive pressure regulator the zero pressure level is lowered approximately 0.2" to 0.4" (0.5 to 1.0 cm.) water pressure with the aviator at rest. Therefore the duration and magnitude of the negative pressure phase is both shortened and decreased but not abolished. The curves also show that there is a greater absolute reduction in the negative pressure phase with the aviator at work. As a result there is a definite decrease in the time during which an inboard leak could occur as well as a decrease in the amount of air that would enter because of the lessoned negative pressure.

On the whole the Pioneer intermittent positive pressure demand regulator in our tests worked well. However, on one small female subject (weight 99 lbs.) who breathed very easily and lightly, the pressure inside the mask apparently did not increase sufficiently during expiration to close completely the demand valve with consequent loss of about 4 liters of oxygen per minute as seen in Table II.

The [illegible] activities [illegible]

This is [illegible] on the principles of [illegible] and comprehensive [illegible]

The [illegible] of the [illegible]

The recommendations [illegible]

[illegible]

In the course of the program [illegible]

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Mr. Holmes stated that he thought some type of spring expiratory valve on the mask is needed to increase the pressure sufficiently to shut off the regulator. However, the next day with the same set up and the same subject the positive pressure demand valve shut off all right. The reason for the different results on the two days was not ascertained when the casing was opened up after the run on the first day. It is possible, however, that on reassembling the regulator the spring might have been replaced in such a way as to decrease the positive pressure required to close the valve.

In order to determine the maximum loss that would occur, if the positive pressure attachment was on at a time when the mask was knocked off an aviator's face so that the oxygen could flow out unhindered, three experiments were carried out. These showed that between 4 and 6 liters per minute would be the maximum loss and that there is some variability as would be anticipated in such a mechanism. A summary of these experiments is presented in Table III.

One of the important performance specifications to prevent undue loss should definitely limit the free flow so that the regulator does not deliver more than 5 or 6 liters per minute S.T.P.D. when the positive pressure valve is on and there is no resistance to the outflow of oxygen.

Constant Positive Pressure Demand Regulator. A regulator is now being developed which will provide a definite and constant positive pressure for use when positive pressure breathing is required for extremely high altitudes. Experimental models have been tested but as yet it is not available in quantity.

Conversion of the Present Emergency Valve to a Quantitative or to an Approximately Quantitative Constant Flow Valve on both the Aro and Bendix Standard Demand Regulator. A better method than that just given of reducing the inherent dangers involved in an extensive use of the demand method is that suggested by the Heidbrink Division of the Ohio Chemical and Manufacturing Company (Air Reduction). They have submitted to us for testing a laboratory modification of the Aro Demand Valve in which the "emergency valve" was altered in two different ways. In both cases the supply for the valve was taken off the reduced pressure inside the regulator and is applicable to the Bendix as well as the Aro regulator.

(a) A kinetic flow indicator with the rate of flow controlled by a suitable (needle-type) valve replaces the present emergency valve. The flow indicator is very small, about one-half the size of the one demonstrated to the committee. In spite of its small size it has a double calibration for the amount of oxygen needed by both an active and inactive aviator at 15, 25, 30, 40 and 42 thousand feet. Our tests showed that these calibrations were accurate and corresponded to the constant flow requirements for active and inactive aviators given in Table IV. Compare these figures with those given in Table I which are the A. A. F. specifications.

The data given in Table IV does not substantiate the claim sometimes made that the demand regulator and mask under comparable conditions of activity is far more economical of oxygen than is the constant flow regulator and mask except at high altitudes. There is indeed a very marked saving in oxygen at 40,000 feet and even more at high altitudes but this saving is made at these altitudes at great risk as recent reports indicate. Flow meters of all types used with a constant flow should have a double calibration, one for an inactive and the other for an active aviator. Such a double calibration has not been found, where used, confusing to the aviator. Some oxygen, of course, can be wasted at low altitudes if the oxygen flow

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is turned up higher than needed for any given altitude. The waste, however, from this source has been greatly exaggerated. Many constant flow regulators have been tested and the increased flow of oxygen at low altitudes as opposed to what would be needed if correctly set rarely exceeds 2 or 3 liters per minute. It is nothing like the waste that can occur from the improper use of the emergency valve on the present demand regulator which will empty out the ship supply in something like 3 to 5 minutes if fully opened up (Table 8, "Physiology of Flight"). In either case aviators must be taught the proper method of using oxygen equipment and the reason therefore.

(b) In the other model submitted to us for testing the emergency valve is replaced by a 3-speed flow valve. This valve was designed to deliver at setting No. 1 approximately 1.5 liters per minute S.T.P.D. between 10,000 and 20,000 feet; from setting No. 2 approximately 3.5 liters per minute S.T.P.D. between 20,000 and 35,000 feet; and from setting No. 3 approximately 5.0 liters per minute S.T.P.D. above 35,000 feet. Our tests show that at these elevations the valve delivered approximately these amounts.

In case this type of valve should be used it is recommended that the rates of flow be reduced to 1.0, 2.5 and 4.0 liters per minute S.T.P.D. respectively for the three settings as these constant flows would be sufficient in conjunction with the demand system even for severe work at the respective altitudes, if there is an economizer bag on the corrugated tube near the masks.

If the recommended rates of flow just suggested are adopted, then setting No. 2, if used at 15,000 feet, would deliver 3.2 liters per minute S.T.P.D. and setting No. 3 at 15,000 feet 6.2 liters per minute S.T.P.D.; the amount wasted at 15,000 feet by using the higher settings is not therefore serious and of course can be prevented by proper training. If the demand mechanism is not working perfectly or if the mask leaks, naturally, very high altitudes should not be attempted.

Economizer Bag on Corrugated Tube Does Not Freeze. The objection has been raised that an economizer bag placed on the corrugated tube near the mask might cause deposition of sufficient ice in the corrugated tube to interfere with the airway which, if true, would be serious. The following experiments at very low temperatures show that no such difficulty from ice formation occurs.

Exp. 1, 11/24/42. Subject: Lt. Margarber, wearing A-14 demand mask with economizer bag on corrugated tube near mask, was in cold chamber for 1 hour and 16 minutes, the temperature of which gradually increased from 41° to 32° F. below zero. Of this time 26 minutes was above 15,000 feet and the highest simulated altitude was 35,000 feet. A small fan was circulating the air in the chamber; a strong blast directly on the aviator's face was not used because at the low temperature the subject could not stand it for more than a short time. No difficulty from ice formation.

Exp. 2, 11/25/42. Subject: Lt. Marbarger, wearing A-14 demand mask with economizer bag on corrugated tube near mask, was in cold chamber 1 hour and 50 minutes with the temperature gradually increasing from 60° F. below zero to 46° F. below zero. Time above 15,000 feet was 1 hour and 14 minutes and the highest simulated altitude was 30,000 feet. The air was circulated by a small fan. No difficulty from freezing.

Exp. 3, 12/1/42. Same subject and same oxygen equipment. Total time in cold chamber 2 hours; above 15,000 feet 1 hour and 17 minutes; highest altitude 20,000 feet. The temperature in chamber gradually decreased from 56° F. to 40° F. below zero. Fan running. No difficulty from freezing.

Exp. 4, 12/2/42. Same subject and equipment. Total time in cold chamber 1 hour; at 15,000 feet 29 minutes. Temperature between 65° F. and 49° F. below zero. Fan running. No difficulty from freezing.

Economizer Bag in Conjunction with Air-Oxygen Demand Valve and Mask. In addition to the conservation of oxygen obtained by the air-oxygen dilutor on any type of demand regulator the saving can be still further increased by the use of an economizer bag placed on the corrugated tubing just below the demand mask. At rest an economizer bag saves around 50 per cent of the oxygen that would be used without the economizer bag. This saving holds whether the dilutor (automix) is on or off and it also does not alter significantly the proportion of oxygen in the air-oxygen mix when the dilutor is on. This saving is of particular value when the aviator has to breathe pure oxygen from ground up to decrease the chance of aeroemphysema developing in high altitude flying. For details of the saving by using an economizer bag see Mayo Aero Medical Unit, Serial Report Series A, no. 3, to Army Air Forces Materiel Center.

Pressure Changes in Mask. Photographic recordings of the pressure changes occuring inside the mask which were obtained by a very delicate apparatus are presented for both the standard Aro and Bendix air-oxygen demand regulator and also for the new Pioneer positive pressure regulator. Curves illustrating all combinations were obtained with automix on and off, with and without constant flow, with and without an economizer bag, and with and without positive pressure; a few of the curves are reproduced to illustrate some of the results.

The negative pressure needed to activate the Pioneer regulator is less, especially with the aviator at work, than needed for the Aro. This series also shows that the magnitude and duration of the negative pressure phase is greatly decreased when a constant flow is used with an economizer bag on the corrugated tube near the demand mask; in fact above 30,000 feet with the aviator at rest there is no negative pressure phase.

The Pioneer intermittent positive pressure air-oxygen regulator decreases the magnitude and definitely shortens the duration of the negative pressure phase. It does not, even with an economizer bag, obliterate the negative pressure phase in any instance although at high altitudes the integrated area of the negative pressure phase is greatly decreased; conversely at lower altitudes less benefit from the intermittent positive pressure is obtained either with or without an economizer bag.

Any method that decreases the negative pressure phase of the demand system obviously decreases the dangers of inboard leaks. However, the constant flow method not only decreases the negative pressure phase, sometimes obliterating it, but also increases the proportion of oxygen in the mixture inhaled at altitudes below 30,000 feet while the positive pressure regulator merely decreases the negative pressure.

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Summary and Recommendations

I. Neither the method of oxygen administration known as the constant flow system with economizer bag nor the system using the standard air-oxygen demand regulator (opening on negative pressure) is satisfactory for all degrees of activity on the part of the aviator at all altitudes under all field conditions. The reasons that neither is completely satisfactory are too well known to need repetition here.

II. Two methods are available for obtaining greater safety, comfort and economy.

1. One method is to combine the constant flow and demand systems and thus permit the aviator to receive the combined advantages which each system possesses separately; two ways of making this combination are described in the text. From a production point of view such a combination is simple and in fact is a sensible and logical improvement in oxygen equipment for aviators as it utilizes well tested principles. Every part of the combined assembly has been extensively field tested so that the limitations as well as the advantages of each are known.

2. Another method is to use the intermittent positive pressure air-oxygen regulator. This is a standard air-oxygen regulator modified in such a way that if a lever has been turned the regulator will open while there is still positive pressure in the mask amounting to 0.1" (0.25 cm.) water. During expiration the flow from the regulator will continue until a positive pressure of 0.2" (0.5 cm.) water is reached. This new Pioneer intermittent positive pressure regulator as yet has had no field tests and therefore cannot at the present time be recommended for more than an extensive trial in spite of the fact that at first sight it seems an excellent piece of apparatus. New data about this regulator are presented in the text.

III. To render both these methods of increasing the safety of the aviator practical the following recommendations are made:

1. The recent improved models of demand type masks A-10-A and A-14 in their various sizes should be adopted and the newly developed universal suspension to helmet be made standard equipment for personal issue after individual fitting at the appropriate training echelon.

2. It is strongly recommended that an economizer bag be used in conjunction with the demand type mask as otherwise the aviator will waste 50% more oxygen. (See Serial Report A-3 of Mayo Aero Medical Unit to Army Air Forces Materiel Center, November 20, 1942.) Furthermore the economizer bag with constant flow available greatly increases the safety of the aviator at all altitudes because if used it greatly reduces and at high altitudes obliterates the negative pressure phase and therefore decreases the danger of an inboard leak and below 30,000 feet increases the proportion of oxygen in the inspired mixture.

   (a) This economizer bag for greatest economy should be placed on the corrugated tube near the mask. The bag need not be made of rubber, and should have an effective capacity of about 700 c.c.; the connecting openings through the corrugated tube should be large and numerous. In

several cold chamber tests no interference from ice formation occurred in experiments, some of which lasted 2 hours, either at ground or at altitudes up to 30,000 feet with the temperature ranging between 65° F. and 32° F. below zero and with the air being circulated by a fan.

(b) An alternate position for the bag is close to the regulator or if desired in a container on the chest which can also house the air-oxygen demand regulator. If the economizer bag is not close to the mask, it is necessary because of accumulation of carbon dioxide to use a smaller bag having an effective volume of not more than 500 cc., thereby decreasing its efficiency in conserving oxygen.

3. The pressure in the oxygen distributing system should not exceed 60 pounds. For this purpose the new small reducing valves which have recently become available should be either on or close to each tank. Recently the universal distributing system has been abandoned and each aviator is to have his own supply tanks and as a result the distributing system will be comparatively short. However, there are many reasons for reducing the oxygen pressure at the tank.

4. In a large bomber regulators with appropriate supplies should be available, of course, at each crew station and in addition extra regulators with long tubes with a plug-in connection at the far end could be located at convenient points within reach of one another to make it more convenient to move about the plane. Such an arrangement is a better system for moving about than a cumbersome walk-around bottle that continually needs refilling, especially as the pressure in the tanks becomes low.

5. To inform the pilot or navigator of the amount of oxygen in the various tanks or groups of tanks for the different members of the crew an electrical system indicating that they are three-fourths, one-half or one-fourth full should be used. Such a system can easily be modified from the one now in use which flashes on a warning light when pressure in the system decreases to 100 pounds.

6. A small double calibrated flow meter (active and inactive) with the oxygen flow controlled by a needle type valve should replace the present emergency valve on the air-oxygen demand regulator so that the aviator may obtain by constant flow in conjunction with an economizer bag the correct amount of oxygen for any altitude. A good but less efficient method of providing a constant flow is to use a three-speed constant flow valve. (See text.)

When used with a demand mask and economizer bag the constant flow valve as described would only be used when the aviator was over 30,000 feet if everything was working perfectly. However, if the mask did not fit the aviator perfectly or if the air-oxygen demand system delivers a "lean mixture", then the aviator would use the constant flow at lower altitudes.

Not only can these arrangements, especially the first one with double calibrated flow meter, be used with the demand mask but they also meet the needs of the aviator who is equipped with the constant flow A-8 series of masks now in such extensive use. In fact, the first set up is far better than the present Pioneer A-8 series of constant flow regulators because the kinetic flow meter indicates the correct amount of oxygen for aviators both at rest and at work.

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7. The new Pioneer intermittent positive pressure air-oxygen demand regulator is small and light enough to be attached, when desired, to the chest of the aviator. If it is on the chest, connection is made by means of a small bore flexible tube from the regulator to a bayonet plug-in on the wall of the plane; these plug-ins would be at appropriate places in the plane and close to the regular air-oxygen demand regulator with constant flow valve. For walking around there would be at convenient places a long length of connecting small bore flexible tubing at the end of which would be a plug-in so that the aviator could go some distance before he had to change over to the next plug-in.

As this intermittent positive pressure instrument is a new type of regulator experimental tests concerning it are given rather extensively in the text. While these tests on a preliminary model indicate that it is an excellent apparatus, yet it can at present be recommended only for extensive trial as soon as the production model is available for field tests.

IV. This Unit has not had an opportunity yet to test the Behnke closed circuit system. However, as Behnke pointed out, it seems to be an economical way of utilizing the constant flow system and therefore deserves careful testing.

V. The above recommendations are intended to be and it is hoped they will prove to be helpful in the progressive development of aviation oxygen equipment while at the same time bearing in mind a change over from present equipment along with the new. The extra duplication of a few inexpensive parts to take care of both the older equipment and any trial equipment like the intermittent positive pressure air-oxygen demand regulators is a negligible item.

VI. The design and flight engineers of Wright Field, of the Navy and of the various manufacturing companies have all done an excellent piece of work and they are cooperating wholeheartedly in an attempt to provide our air forces with the very best possible oxygen equipment. To have the best means constant change as new improvements in design and in construction are developed with increased knowledge of the subject. It is to aid this purpose and not to criticize that the suggestions here made are offered.

Table I.

Altitude	21 A-9A Reg. Setting adjusted to altitude L./min. N.T.P.*	A-8A and A-9A Reg. Flow at altitude L./min. N.T.P.*	Reworked A-8 and A-9 Flow at altitude L./min. N.T.P.*	Actual delivery of one of A-8 series sent us by Pioneer No.(B3)2806 1C-1B-02343 S.T.P.D.**
Ground	0.0			
10,000	1.43	1.6 approx.	2.9 approx.	1.4
20,000	1.89	2.2 "	3.3 "	1.6
30,000	2.74	3.2 "	3.6 "	1.6
35,000	2.91			1.8
40,000	3.28			
Reference	Page 75	Page 84	Page 85	Mayo Aero Medical Unit

*N.T.P. Usually refers to the normal or standard temperature and pressure at sea level of the United States Standard Atmosphere: 760 mm. 15° C. (Pub. No. 218 and 538).

**S.T.P.D. refers to standard temperature and pressure dry: 760 mm. 0° C. and dry.

Table II.

Automix:	Scholander O_2% inspired mixture Tube On	Tube Off	Mask On	Mask Off	Oxygen used from tank Liters per minute S.T.P.D. On	S.T.P.D. Off	Ambient On	Ambient Off
Elevation			Positive Pressure Off					
15,000	34			99	0.59	3.30	1.33	7.46
25,000	69			98	1.41	2.04	5.18	7.50
30,000	99			98	1.62	1.61	7.83	7.78
33,000	99			98	1.42	1.41	8.23	8.17
			Positive Pressure On					
15,000	41			99	1.35	7.15	3.05	16.17
25,000	72			99	2.02	5.36	7.43	19.70
30,000	99			98	5.57	5.43	26.91	26.23
33,000	99			99	5.30	5.17	30.17	29.95

Table III

Elevation	Exp. I, Flight 177 L./min. STPD AUTOMIX On	Off	Exp. II, Flight 180 L./min. STPD AUTOMIX On	Off	Exp. III, Flight 182 L./min. STPD AUTOMIX On	Off
Ground	5.50	5.54	3.84	5.54	5.75	6.18
15,000	4.90	4.94	3.89	4.81	5.13	5.36
25,000	4.54	4.55	4.48	4.47	4.97	4.95
30,000	4.40	4.43	4.41	4.38	4.93	4.83
33,000	4.36	4.37			4.84	4.77
40,000	4.19	4.17				

Table IV.

	Standard Oxygen Requirement Recommended by the Mayo Aero Medical Unit for Use with a Constant Flow System Using an Economizer Bag				Amount Oxygen Required when Using Demand Regulator with Subject at Rest, Assuming a Respiratory Volume 9 L/m.(3)	
	Liters per Minute					
	Inactive		Active			
Elevation	(1) S.T.P.D.	(2) Lung	(1) S.T.P.D.	(2) Lung	Pioneer A-12 L/min. N.T.P.	Aro A-13 L./min. N.T.P.
Ground	0.0	0.0	0.0	0.0	1.62	0.7
10,000	0.5	0.9	1.0	1.8	1.36	1.06
15,000	0.8	1.8	1.6	3.6		
20,000	1.1	3.0	2.1	6.8	1.37	2.23
25,000	1.4	5.2	2.9	10.7		
30,000	1.8	8.7	3.6	17.4	2.58	2.64
35,000	2.2	14.4	4.4	28.8	1.66	1.66
40,000	2.5	23.0	5.0	46.1	1.18	1.18
42,000	2.7	28.8	5.4	57.6		

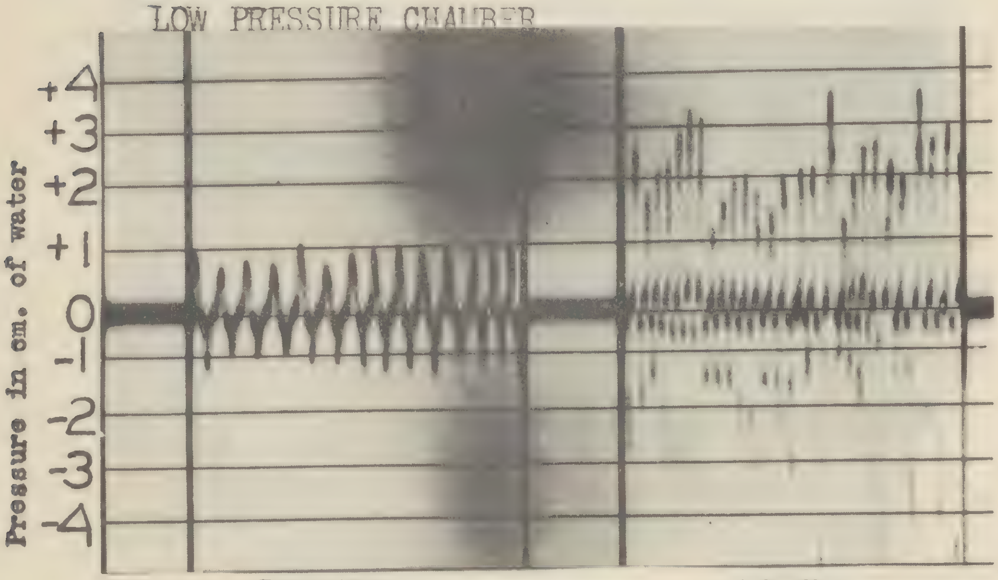
(1) Measured at 760 mm. 0° C. and dry - S.T.P.D.
(2) Measured at ambient barometer, 37° C. and saturated with moisture.
(3) Taken from Table 7, page 75, "Physiology of Flight," Aero Medical Research Laboratory, Wright Field.

PRESSURE CHANGES IN BLB CHIN TYPE MASK

AT REST AND AT WORK(1200 ft.lbs./min.)

AT VARIOUS SIMULATED ALTITUDES. IN THE

LOW PRESSURE CHAMBER

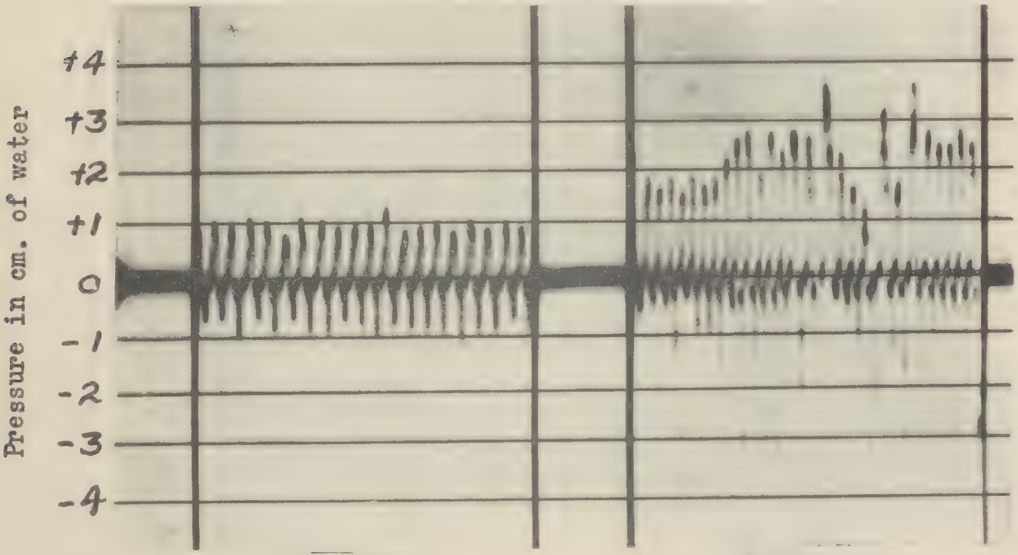


RESTING
FLOW - 0.8 L/min.
- 15,000 Inactive

WORKING
FLOW - 1.6 L/min.
- 15,000 Active

ALTITUDE - 15,000 feet

Mayo Aero-Medical Unit
Boothby, Flinn and Bratt
May 15, 1942



RESTING
FLOW- 1.1 L/min.
- 20,000 Inactive

WORKING
FLOW - 2.1 L/min
- 20,000 Active

ALTITUDE - 20,000 feet

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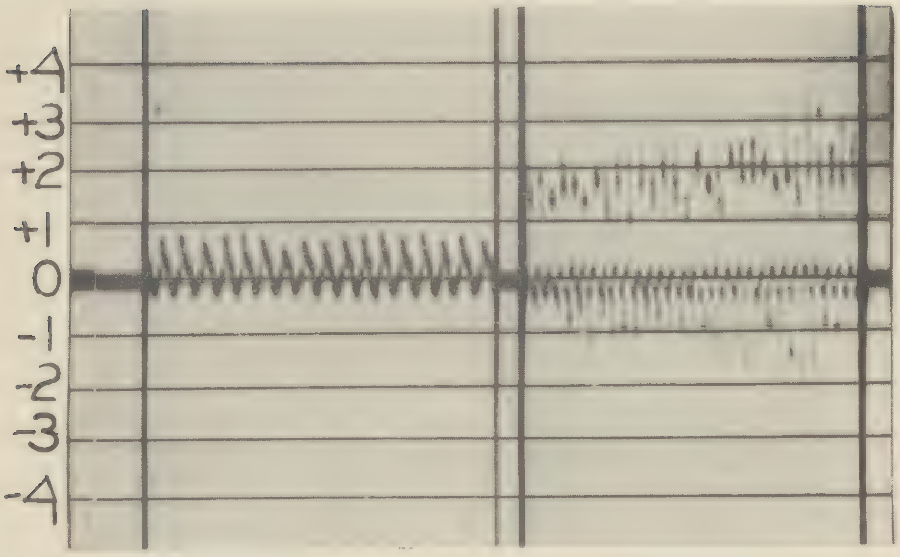
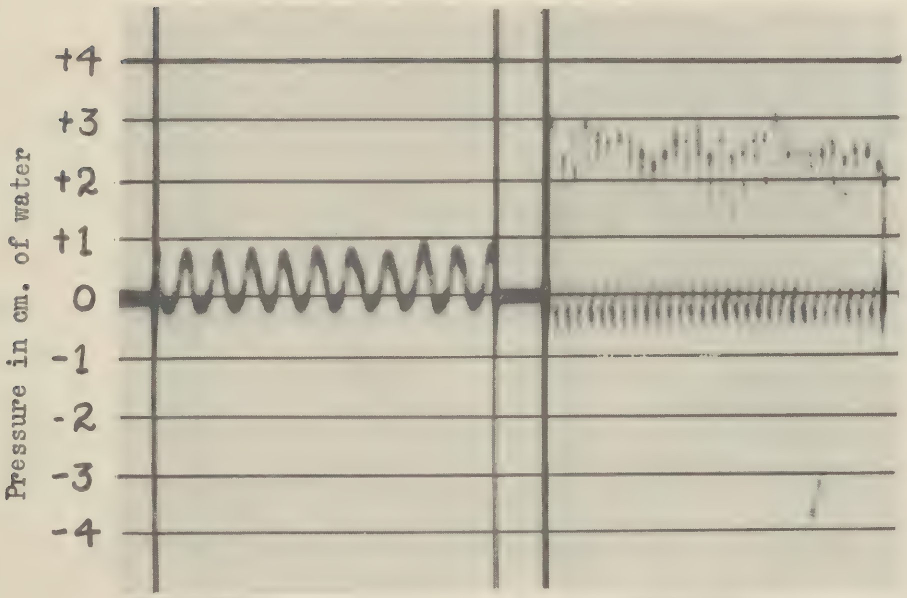
Boothby, Flinn and Bratt
May 15, 1942



RESTING
FLOW - 1.4 L/min
- 25,000 Inactive

WORKING
FLOW - 2.9 L/min
- 25,000 Active

ALTITUDE - 25,000 feet

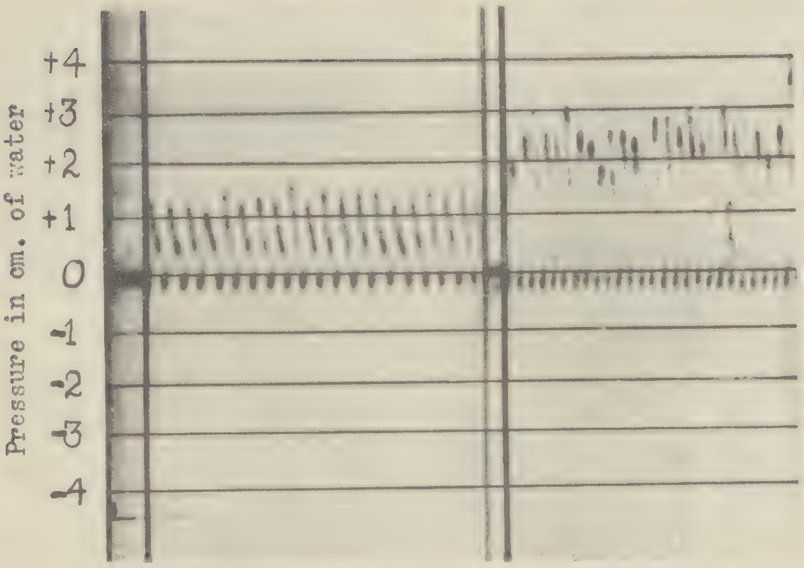


RESTING
FLOW - 1.8 L/min
- 30,000 Inactive

WORKING
FLOW - 3.6 L/min
- 30,000 Active

ALTITUDE - 30,000 feet

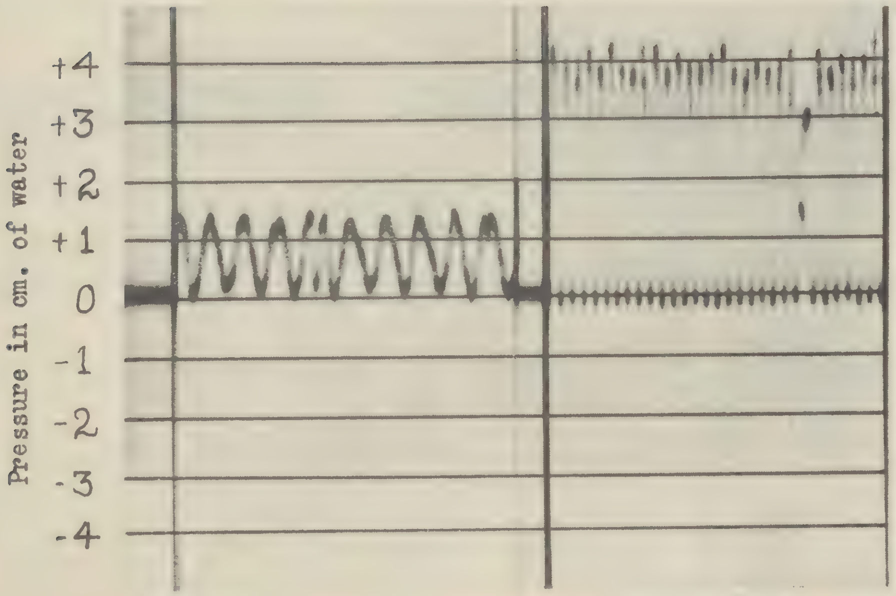
Mayo Aero-Medical Unit
Boothby, Flinn and Bratt
May 15, 1942



RESTING
FLOW - 2.2 L/min
- 35,000 Inactive

WORKING
FLOW - 4.4 L/min
- 35,000 Active

ALTITUDE - 35,000 feet

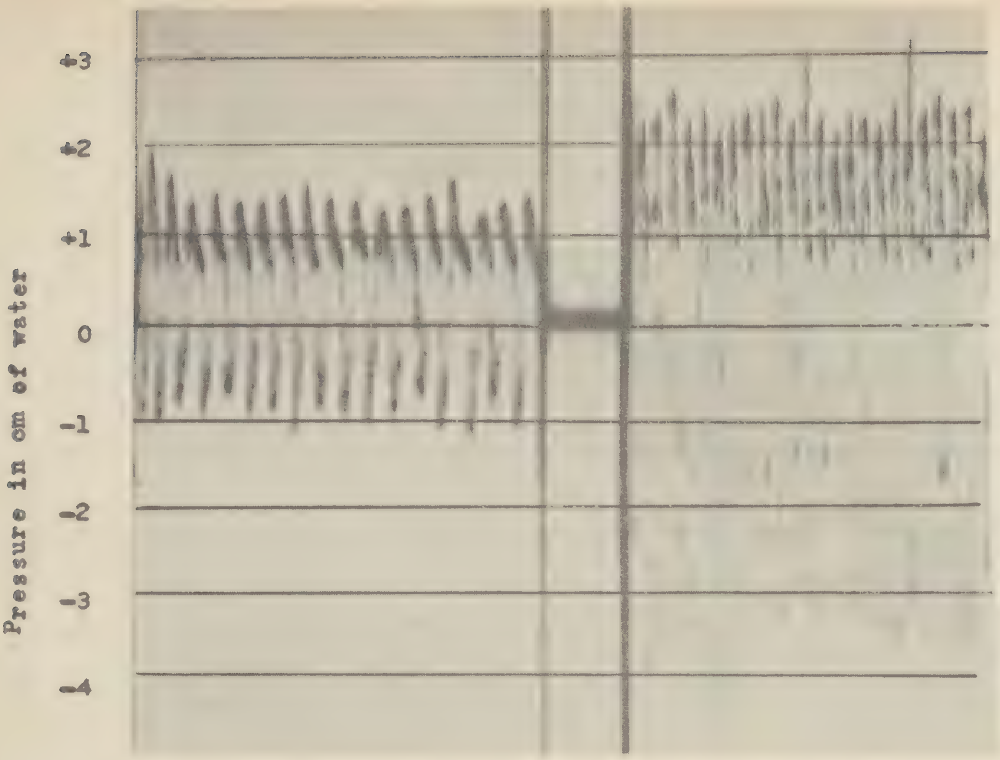


RESTING
FLOW - 2.5 L/min
- 40,000 Inactive

WORKING
FLOW - 5.0 L/min
- 40,000 Active

ALTITUDE - 40,000 feet

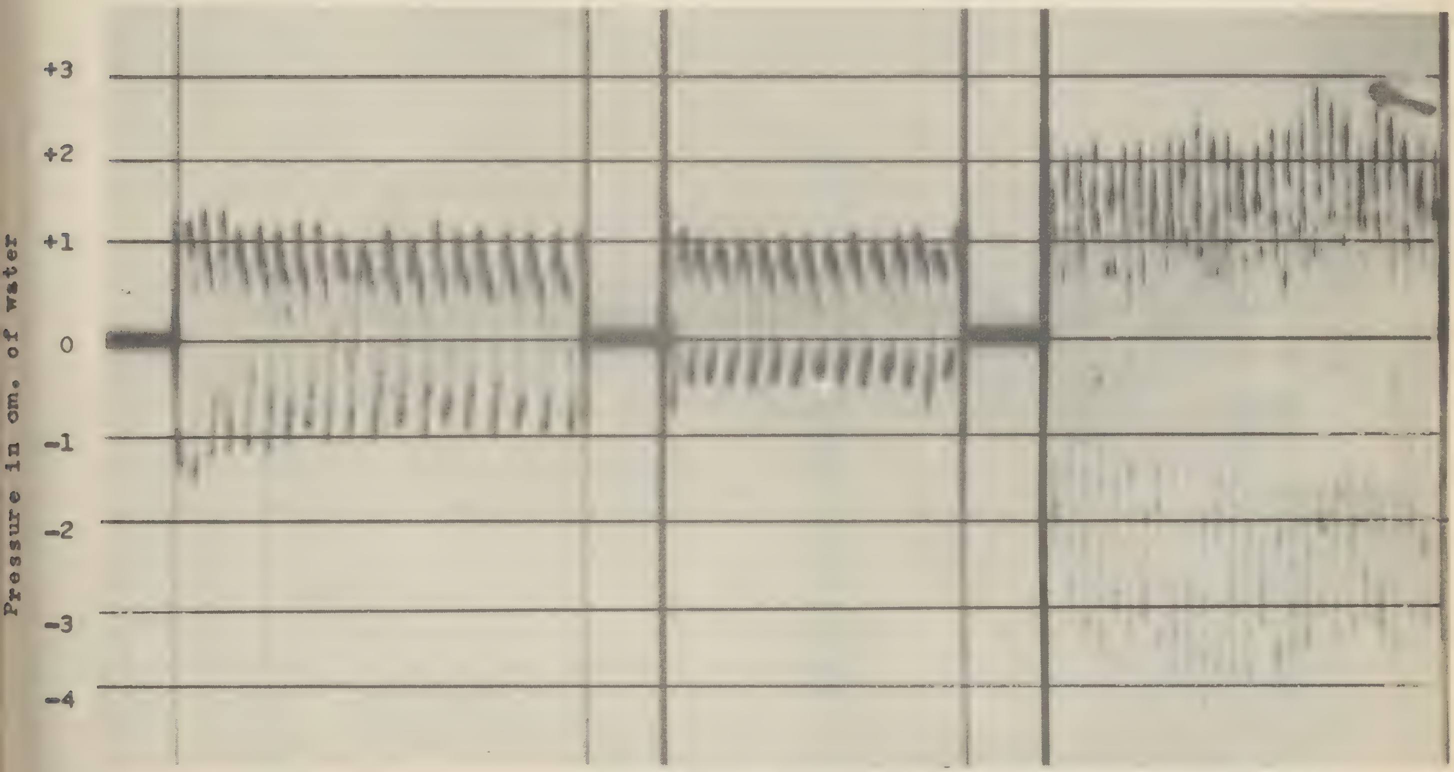
XV 1c



RESTING

WORKING(1200 ft. lbs/min.

ALTITUDE - 15000 Feet



RESTING

RESTING
(AUTOMATIC REGULATOR
TURNED OFF)

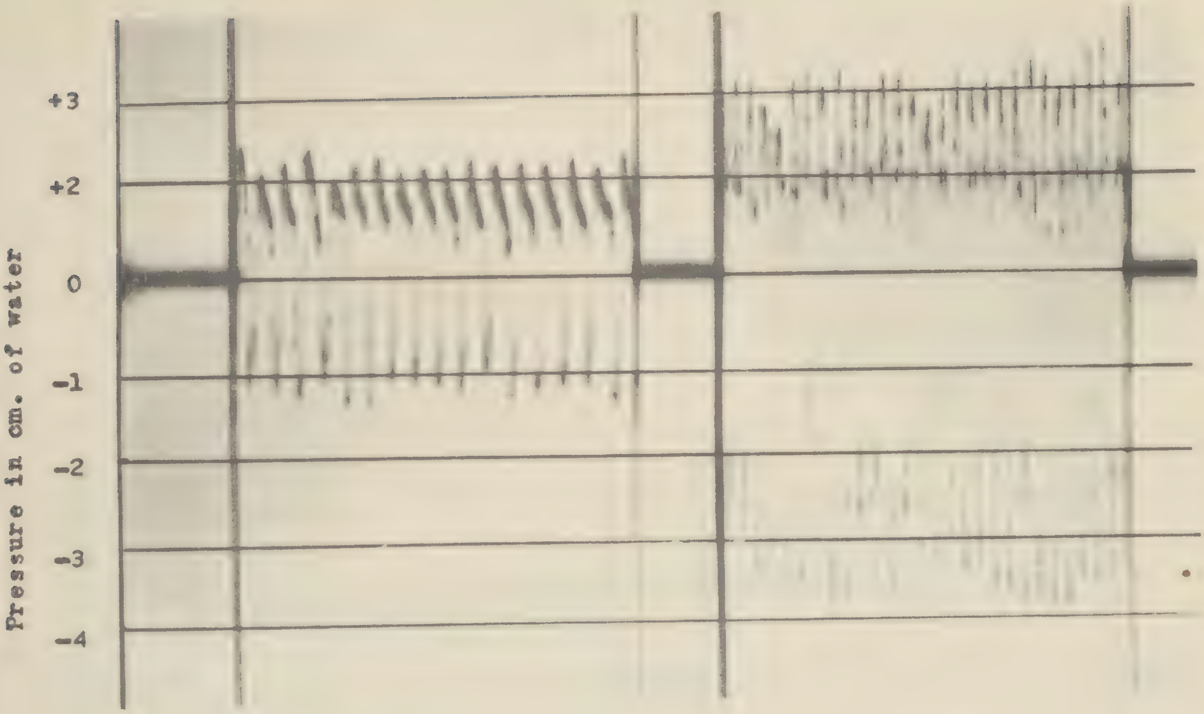
WORKING
(1200 ft. lbs/ min)

JUNE 3, 1942

ALTITUDE - 25000 Feet

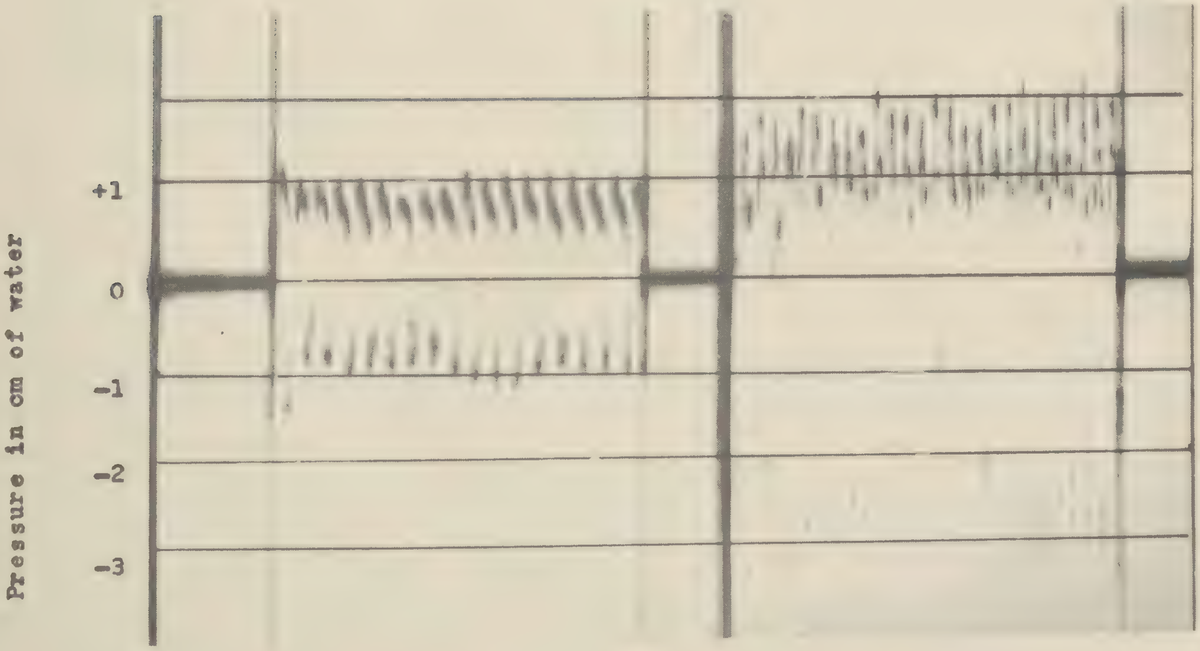
BLB DEMAND ARMY AUTOMATIC REGULATOR TYPE A-12 SERIAL 127 ARO EQUIPMENT CORPORATION

MAYO AERO-MEDICAL UNIT
ROCHESTER MINN.



RESTING WORKING (1200 ft lbs/ min)

ALTITUDE - 30000 Feet



RESTING WORKING 1200 ft. lbs/ min)

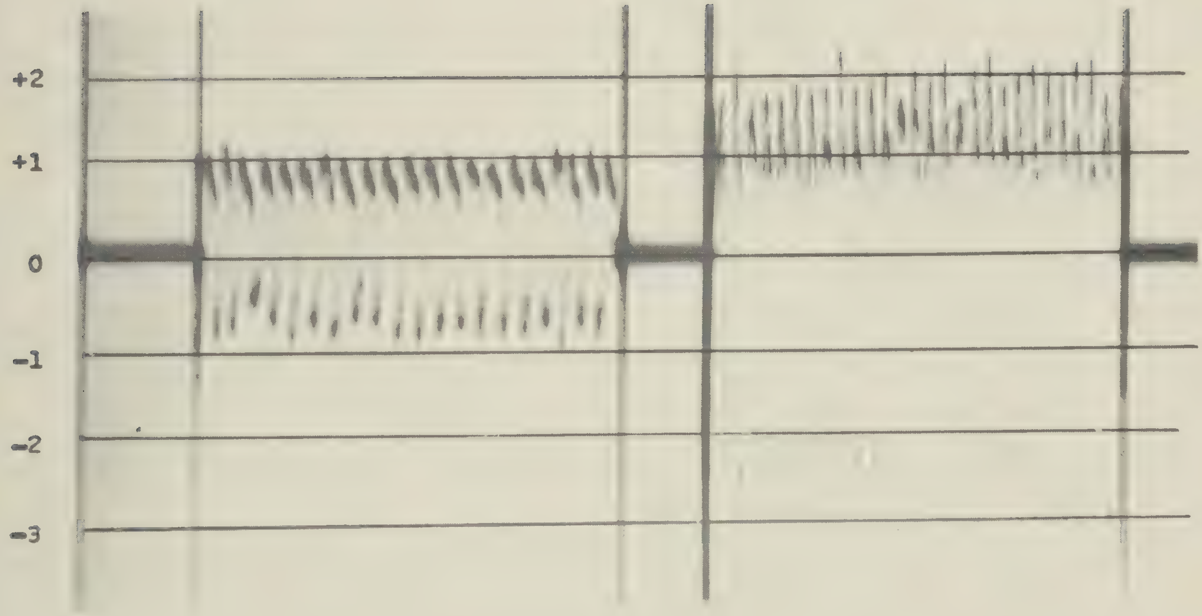
ALTITUDE - 35000 Feet

JUNE 3, 1942

DEMAND ARMY AUTOMATIC REGULATOR TYPE A-12 SERIAL 127 ARO EQUIPMENT CORPORATION

2 b

MAYO AERO - MEDICAL UNIT
ROCHESTER, MINN



RESTING

WORKING (1200 ft lbs/ min)

ALTITUDE - 40000 Feet

JUNE 3, 1942

BLB DEMAND ARMY AUTOMATIC REGULATOR TYPE A-12 SERIAL 127 ARO EQUIPMENT CORPORATION

XV- 2 c

Report No. 2
April 20, 1943

MAYO AERO MEDICAL UNIT

Report to

SUBCOMMITTEE ON OXYGEN AND ANOXIA
NATIONAL RESEARCH COUNCIL

COMPARISON OF ALVEOLAR OXYGEN PRESSURES, OXIMETER READINGS AND PERCENTAGE OF SATURATION OF HEMOGLOBIN

by

Walter M. Boothby, M. D., Responsible Investigator, and
F. J. Robinson, M. D., First Assistant

I. In October 1942 Code, Power, Sturm and Wood of the Mayo Aero Medical Unit ran a series of fifteen experiments on the percentage saturation of hemoglobin in arterial blood (cubital artery) and simultaneous readings on a modified Milliken oximeter known as the Coleman Model 17, No. 5769.

This data is reproduced here as Figure I (chart III-8A) and shows that there is excellent correlation between the percentage saturation of the hemoglobin read off directly on this particular oximeter (manipulated under ideal conditions by trained personnel) and as determined by careful blood gas technic. Only one of the determinations falls beyond the range of ± 5 percentage points and ten out of the fifteen observations are within ± 2 percentage points.

II. The present investigations have been confined to determining whether this same oximeter which showed such close correlations with actual blood gas determinations would show a correlation with the partial pressure of oxygen in the alveolar air.

The averages of the observations obtained at the different elevations of the percentage saturations of the hemoglobin as read from the oximeter usually fell within 1 or 2 percentage points of Dill's oxygen dissociation curve (pH 7.4) when plotted against the average of the partial pressure of oxygen in the alveoli whether at rest or at work and whether the alveolar air was obtained by the Haldane or by the bag-rebreathing method. However, the individual observations of the different series show a considerable and apparently, for the most part, accidental scatter; this scatter is sufficiently great to render an individual observation rather doubtful as a criterion of a subject's safety at simulated high altitudes in chamber work.

The vagaries of the oximeter itself and the difficulty of obtaining alveolar air samples that truly represent a mean value of the oxygen partial pressure are complicating factors. At low altitudes there is the added difficulty due to the fact that the dissociation curve is appreaching its asymptote and that therefore accidental high readings are less likely to occur and compensate for the accidental low readings due in part to blood being exposed to oxygen in some of the deeper alveoli which is considerably below the average that would be obtained in an alveolar air sample. Finally the oximeter does not reflect the influence of alteration in pH on the dissociation curve of hemoglobin.

III. Two distinct methods of obtaining alveolar air samples in the low pressure chamber at ground level (1,000 feet) and at different altitudes have been used; also the effect of light work was studied using both alveolar air methods.

A. One method of obtaining an alveolar air sample is that commonly known as the Haldane and Priestley method: the alveolar air is obtained by giving a quick, deep expiration into a 3/4 inch hose (with simple mouth piece) about 4 feet long; after the expiration the subject closes the mouth end of the tube with his tongue and the sample of the last part of breath drawn out into a mercury sampling tube. Two samples are usually averages, one obtained with expiration starting at the beginning and the other at the end of a respiratory cycle. To render the method slightly simpler to manipulate we used a special valve which could be snapped at end of expiration to close off the sample and so constructed that during the expiration the entire tube is smooth and contains no pockets.

B. The other method was to attach a 5 liter rubber bag onto the same valve mentioned above instead of the long hose tube. The subject expired deeply into the bag, inhaled and again expired. In one series this was done for three expirations into bag and two inhalations from bag, closing the valve at end of third expiration, and in another series there were three inhalations and four expirations.

IV. The data thus obtained is presented in a series of charts which are in the main self-explanatory and therefore need little additional description.

A. Figure II (chart III-10A) shows the averages obtained from 259 alveolar air determinations by the Haldane method; the oximeter was read just before collecting the alveolar air samples. In 202 of these observations the oximeter was arbitrarily set at 95 per cent saturation with the subject breathing air at ground level (1,000 feet) while in 57 observations the oximeter was set at 100 per cent with the subject breathing oxygen; the oximeter in this series read on the average 97 per cent when the subject returned to breathing air at ground level instead of the 95 per cent arbitrarily set for breathing air.

The average figures plot very satisfactory along the oxygen dissociation curve of Dill for a pH of 7.4.

B. Figure III (chart III-10B) shows the individual plottings of the 259 observation averages in Figure II. There is, as can be seen, a very definite scatter of the individual observations which is smoothed out in the averages of the preceding chart. Figure IV (chart III-10Ba) gives possibly a clearer picture of the correlation of those observations of Figure III which were made with the oximeter set on oxygen.

C. Figure V (chart III-10C) shows the average values of 105 observations. Of these, 58 observations were obtained by exhaling deeply three times (inhaling twice) into a 5 liter bag and 48 observations by exhaling deeply four times (inhaling thrice) into the bag. The average figures from both the three and the four series are practically identical and when plotted show very excellent correlation with Dill's curve for pH of 7.4 although there is a slight indication that this is a tendency for the curve to shift somewhat to the left at 12,000 and 15,000 feet, presumably from the effect of hyperventilation.

11. [illegible]

2. [illegible]

3. [illegible]

4. [illegible]

5. [illegible]

[illegible]

5. [illegible]

6. [illegible]

D. Figure VI (chart III-10D) shows the individual observations comprising the average values given in Figure V. The plot shows a lesser spread of the individual observations by the bag-rebreathing method than by the Haldane method shown in Figure III. Figure VII (chart III-10Da) gives possibly a clearer picture of the degree of correlation of the data shown in Figure VI.

E. In Figure VIII (chart III-10E) are shown the averages of 207 determinations of which 40 were made by the Haldane method at sitting rest, 40 by the bag-rebreathing method (using three breaths) at sitting rest, 63 by the Haldane method with the subject doing work equivalent to walking about two and one-half miles per hour (stepping up on an 8 inch step) and finally 64 by the bag-rebreathing method (three breaths) at similar degree of work.

The plotted results show a very good correlation both at rest and at work by both methods with Dill's dissociation curve (pH 7.4). The experiments at work showed a lower degree of percentage saturation of the hemoglobin by the oximeter than did those at rest but there was a corresponding decrease in the partial pressure of oxygen in the alveolar air by both alveolar air methods so that the experiments at work as well as those at rest agree closely with Dill's dissociation curve at pH 7.4.

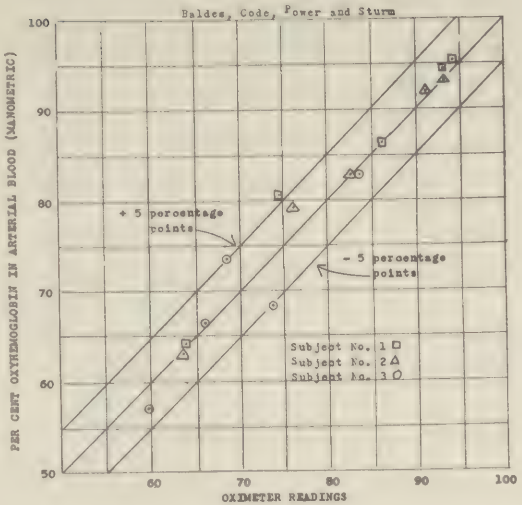
SUMMARY

The special oximeter calibrated and used in the Mayo Aero Medical Unit gives on the average a percentage saturation of hemoglobin in excellent agreement with the partial pressure of oxygen in the alveolar air whether the subject is at rest or at work or whether the alveolar air was obtained by the Haldane-Priestley or bag-rebreathing method. The plots of the individual observations show a considerable scatter but a variability after all surprisingly small considering the possibilities of error both in the oximeter and in the obtaining of a corresponding alveolar oxygen pressure.

COMPARISON OF OXIMETER READINGS AND ALVEOLAR OXYGEN PRESSURES

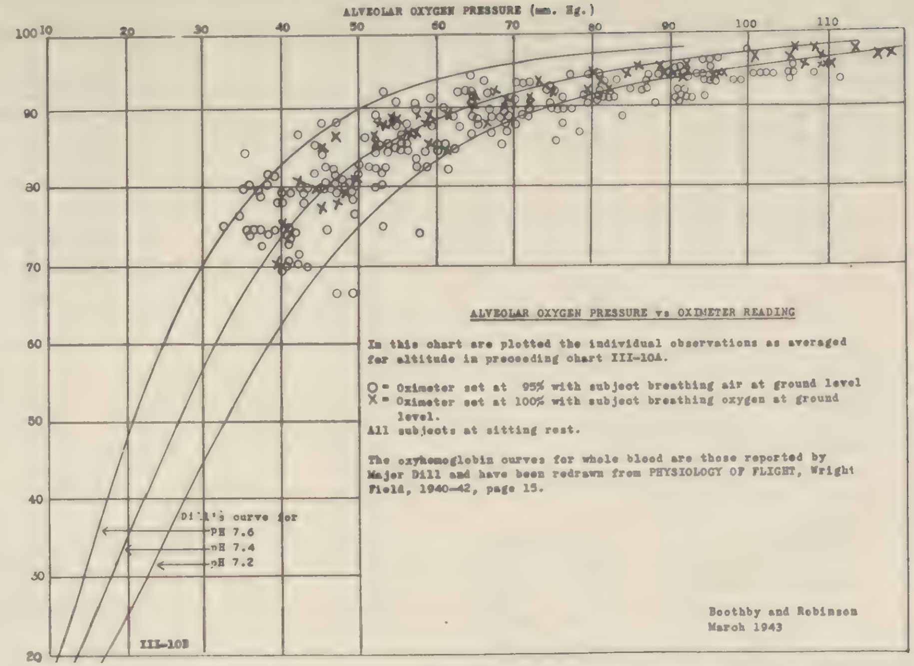
CALIBRATION OF OXIMETER

Baldes, Code, Power and Sturm



This chart shows the calibration data on the oximeter used in this laboratory (Coleman Model 17, 5769) obtained by analysis of the oxygen capacity and content of the arterial blood by the manometric technic of Van Slyke and Neill. Subjects at lying rest.

Boothby and Robinson March, 1943.



ALVEOLAR OXYGEN PRESSURE vs OXIMETER READING

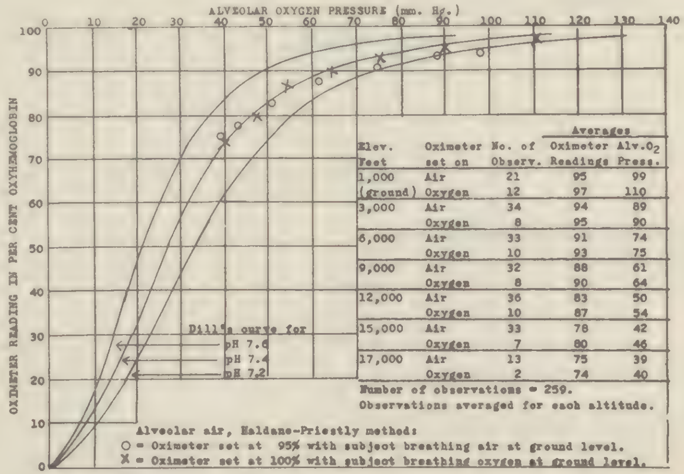
In this chart are plotted the individual observations as averaged for altitude in preceding chart III-10A.

○ = Oximeter set at 95% with subject breathing air at ground level
X = Oximeter set at 100% with subject breathing oxygen at ground level.

All subjects at sitting rest.

The oxyhemoglobin curves for whole blood are those reported by Major Dill and have been redrawn from PHYSIOLOGY OF FLIGHT, Wright Field, 1940–42, page 15.

Boothby and Robinson
March 1943



Elev. Feet	Oximeter set on	No. of Observ.	Averages Oximeter Readings	Averages Alv. O_2 Press.
1,000 (ground)	Air	21	95	99
	Oxygen	12	97	110
3,000	Air	34	94	89
	Oxygen	8	95	90
6,000	Air	33	91	74
	Oxygen	10	93	75
9,000	Air	32	88	61
	Oxygen	8	90	64
12,000	Air	36	83	50
	Oxygen	10	87	54
15,000	Air	33	78	42
	Oxygen	7	80	46
17,000	Air	13	75	39
	Oxygen	2	74	40

Number of observations = 259.
Observations averaged for each altitude.

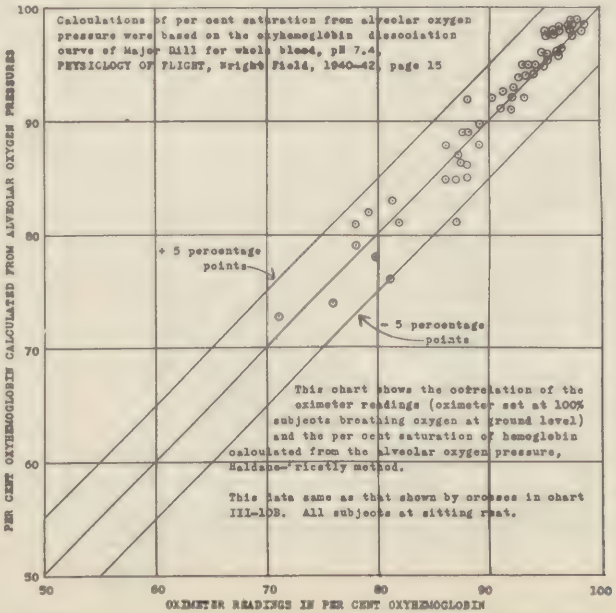
Alveolar air, Haldane-Priestly method:
○ = Oximeter set at 95% with subject breathing air at ground level.
X = Oximeter set at 100% with subject breathing oxygen at ground level.

The individual observations comprising the averages are shown in chart III-10B. All subjects at sitting rest.

The oxyhemoglobin dissociation curves for whole blood are those reported by Major Dill and have been redrawn from PHYSIOLOGY OF FLIGHT, Wright Field, 1940–42, page 15.

III-10A

Boothby and Robinson March, 1943,



Calculations of per cent saturation from alveolar oxygen pressure were based on the oxyhemoglobin dissociation curve of Major Dill for whole blood, pH 7.4, PHYSIOLOGY OF FLIGHT, Wright Field, 1940–42, page 15

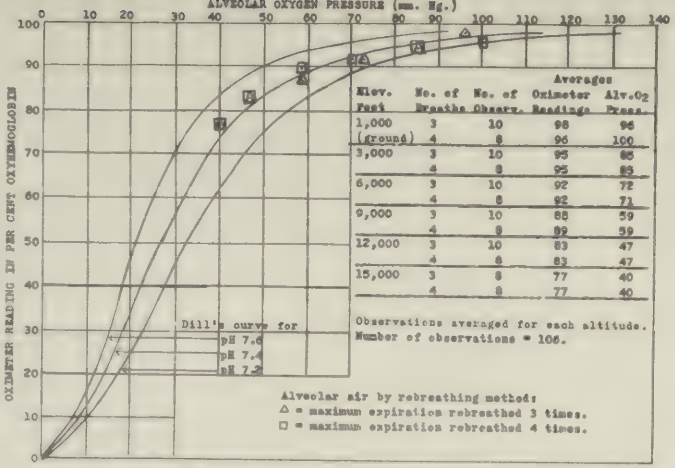
This chart shows the correlation of the oximeter readings (oximeter set at 100% subjects breathing oxygen at ground level) and the per cent saturation of hemoglobin calculated from the alveolar oxygen pressure, Haldane–Priestly method.

This data same as that shown by crosses in chart III-10B. All subjects at sitting rest.

III-10Ba

Boothby and Robinson March 1943.

COMPARISON OF OXIMETER READINGS AND ALVEOLAR OXYGEN PRESSURES



Elev. Feet	No. of Breaths	No. of Observ.	Averages Oximeter Readings	Averages Alv. O_2 Press.
1,000	3	10	98	96
(ground)	4	8	96	100
3,000	3	10	95	86
	4	8	95	85
6,000	3	10	92	72
	4	8	92	71
9,000	3	10	88	59
	4	8	89	59
12,000	3	10	83	47
	4	8	83	47
15,000	3	8	77	40
	4	8	77	40

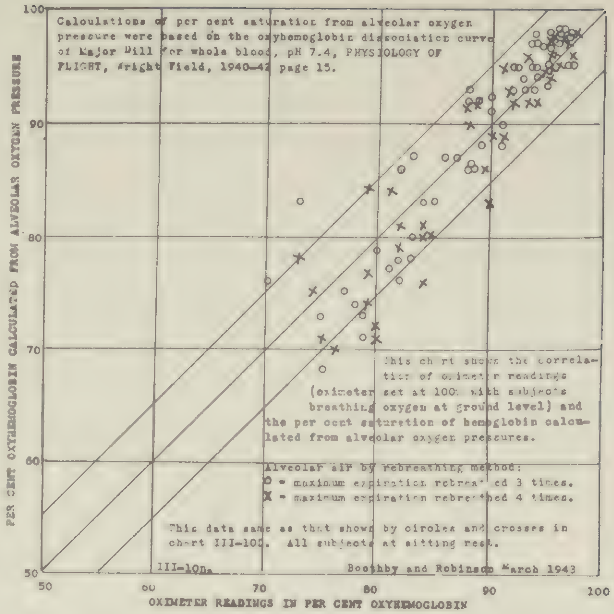
Observations averaged for each altitude.
Number of observations = 106.

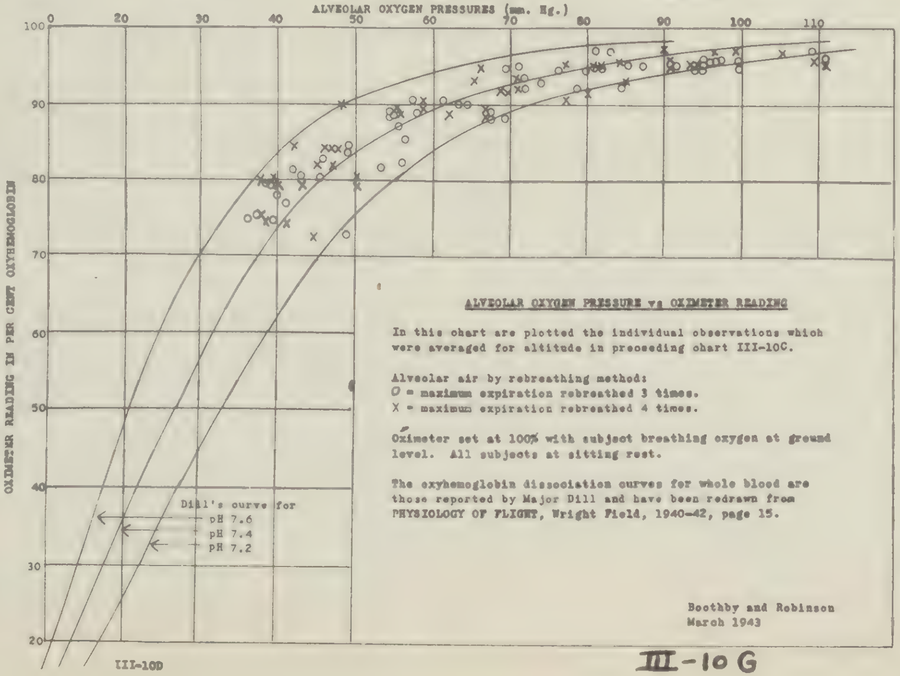
Oximeter set at 100% with subject breathing oxygen at ground level. The individual observations comprising the averages are shown in chart III-10D. All subjects at sitting rest.

The oxyhemoglobin dissociation curves for whole blood are those reported by Major Dill and have been redrawn from PHYSIOLOGY OF FLIGHT, Wright Field, 1940-42, page 15.

III-10C

Boothby and Robinson
March 1943





ALVEOLAR OXYGEN PRESSURE vs OXIMETER READING

In this chart are plotted the individual observations which were averaged for altitude in preceeding chart III-10C.

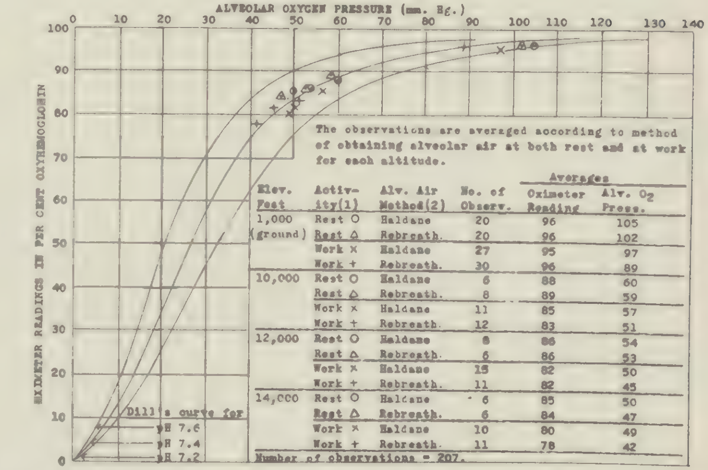
Alveolar air by rebreathing method:
O = maximum expiration rebreathed 3 times.
X = maximum expiration rebreathed 4 times.

Oximeter set at 100% with subject breathing oxygen at ground level. All subjects at sitting rest.

The oxyhemoglobin dissociation curves for whole blood are those reported by Major Dill and have been redrawn from PHYSIOLOGY OF FLIGHT, Wright Field, 1940-42, page 15.

Boothby and Robinson
March 1943

III-10D



The observations are averaged according to method of obtaining alveolar air at both rest and at work for each altitude.

Elev. Feet	Activity(1)	Alv. Air Method(2)	No. of Observ.	Averages Oximeter Reading	Averages Alv. O_2 Press.
1,000	Rest O	Haldane	20	96	105
(ground)	Rest △	Rebreath.	20	96	102
	Work ×	Haldane	27	95	97
	Work +	Rebreath.	30	96	89
10,000	Rest O	Haldane	6	88	60
	Rest △	Rebreath.	8	89	59
	Work ×	Haldane	11	85	57
	Work +	Rebreath.	12	83	51
12,000	Rest O	Haldane	8	86	54
	Rest △	Rebreath.	6	86	53
	Work ×	Haldane	15	82	50
	Work +	Rebreath.	11	82	45
14,000	Rest O	Haldane	6	85	50
	Rest △	Rebreath.	6	84	47
	Work ×	Haldane	10	80	49
	Work +	Rebreath.	11	78	42

Number of observations = 207.

(1) Rest - sitting in chair. Work - stepping onto 5 inch stool 16 times per minute with metronome set at 80 to obtain 5 beats to alternate legs used for elevation.
(2) Alveolar air methods: (a) Haldane-Priestly.
(b) Rebreathing method with single expiration rebreathed 3 times.

Oximeter set at 100% with subject breathing oxygen at ground level.
The oxygen dissociation curves for whole blood are those reported by Major Dill and have been redrawn from PHYSIOLOGY OF FLIGHT, Wright Field, 1940-42, page 15.

III-10E

Boothby and Robinson
March 1943

III-10G

Report No. 3
April 20, 1945

MAYO AERO MEDICAL UNIT

Report to

SUBCOMMITTEE ON OXYGEN AND ANOXIA
NATIONAL RESEARCH COUNCIL

SUMMARY OF THE DEVELOPMENT OF POSITIVE PRESSURE CLOSED CIRCUIT JACKET TO BE USED IN ATTEMPTING TO ATTAIN ALTITUDES AS HIGH AS 50,000 FEET

by

Walter M. Boothby, M.D., Responsible Investigator

I. The work summarized here was carried out in the Mayo Aero Medical Unit and has been reported in detail to the Army Air Forces Materiel Center under Contract No. W535-ac-25829 in reports numbered Series A, No. 4, 4a, 4b, 4c, 4d, 4e, 4f and 4g by the following investigators: E.W.Erickson, J.P. Marbarger, M.H. Power, F.J. Robinson, Grace Roth, D.W.Rucker, C.B.Taylor and Henry Wagner.

During my absence in January and February Drs. E.J.Baldes and C.F.Code acted for me as Responsible Investigator.

The possibility of utilizing a closed circuit rebreathing positive pressure jacket constructed on the principles described here was first suggested in this laboratory by 1st Lt. C.B.Taylor, M.C. He in conjunction with 2nd Lt. J.P. Marbarger, A.A.F., Liaison Officers from the Air Surgeon's Office, carried out with the cooperation of various other members of the Mayo Aero Medical Unit the work briefly summarized here.

Our thanks are due to Professor M. B. Visscher and to Professor L.G. Rigler of the University of Minnesota for their cooperation in carrying out certain pressure experiments on dogs and in obtaining at ground level roentgen kymograph records of cardiac contraction.

II. Construction and description of apparatus.

A positive pressure jacket was constructed to operate on the closed circuit principle as an aid in increasing the altitude attainable to decrease the fatigue caused by positive pressure breathing first carried out by Gagge.

A rubberized bag with a volume of approximately 11 liters encircles the entire trunk of the body. This rubberized bag is surrounded on the outside by a flight jacket which serves as an outer foundation garment to give rigidity to the outer wall of the bag for counter-pressure. The inner wall of the rubberized bag fits snuggly to the body so that when the jacket is inflated it exerts the desired positive pressure evenly on the chest and abdomen. Two crotch straps attached to the jacket prevent it from creeping up the trunk of the body.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Oxygen from a constant flow or a constant pressure demand regulator enters the jacket. The mask is connected to the pressure jacket by two pieces of corrugated tubing with inspiratory and expiratory valves at the connection to the jacket and with a shell natron container on the expiratory tube. On inspiration oxygen passes from the jacket through one of the corrugated tubes to the mask and into the lungs. Gas from the lungs is expired through the other corrugated tube to the shell natron container which is fastened to the front of the jacket in a convenient manner and then back into the pressure jacket through the expiratory valve. This arrangement facillitates the maintenance of an even pressure because the air which enters the lungs comes from the bag and goes into it on expiration without much change in total air volume of the jacket-lung closed circuit system. In consequence the total pressure in the system can be regulated easily by a spring-loaded release valve to maintain any desired pressure in the system from 0 to +40 cm. water without much fluctuation ($\pm$ 2 cm.) from the desired mean pressure.

This system renders breathing against a positive pressure as great as 30 to 40 cm. water pressure relatively easy and non-fatiguing because of the counter-pressure on chest and abdomen; on inspiration the volume of the jacket is decreased, thus allowing for chest expansion; during expiration the volume of the jacket is increased as a result of gas passing from the lungs back into the jacket.

III. Results.

1. The comfort and efficiency of persons wearing the positive pressure jacket at altitude are brought out by the ease with which the operator could perform femoral arterial punctures after twenty minutes at 46,000 feet and after fifteen minutes at 50,000 feet. Both operator and subjects were always mentally alert and the operator was able to perform delicate procedures with fine dexterity and walk around in the chamber readily. This efficiency and comfort of the operator is well shown in the movie of arterial punctures at 50,000 feet.

2. Subjects are able to breathe positive pressures of 40 cm. water in the positive pressure jacket for periods as long as one and one-half hours with very minimal fatigue especially at high altitudes; in contrast, while breathing against similar positive pressure (pressure rebreather bag) without chest and abdominal counter-pressure most subjects become markedly fatigued under pressures of 28 to 40 cm. for periods as short as from five to fifteen minutes.

3. No evidence of circulatory collapse has been noted in numerous experiments when using positive pressures as great as 40 cm. of water when wearing the jacket for chest and abdominal counter-pressure while it occurred in two out of ten experiments using pressures of 28 to 40 cm. water within five and ten minutes after positive pressure breathing was started without a jacket for counter-pressure.

4. The responses of the blood pressure, pulse, venous pressure and circulation time while breathing positive pressure with and without a vest are presented in tabular form.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Subject:	Time exposed to pressure CBT	JPM	Pulse CBT	JPM	B. P. CBT	JPM	Venous pressure cm. H_2O CBT	JPM	Circulation time arm to lung, Sec. CBT	JPM
Normal (Ground)			76	80	126/84	126/84	7	$5\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$
Positive pressure of 22 to 30 cm. H20. No counter pressure (ground)	7	8	100	94		116/76		23		13
Positive pressure of 22 to 30 cm. H20 with jacket counter-pressure (ground)	7	30	96	96	140/110	126/90		29	10	
Positive pressure at altitude of 40,000 feet with jacket. Counter-pressure at 27 to 30 cm. H20		22		106		140/108				

5. The roentgen kymograph revealed in three experiments on one subject at ground level no change in cardiac contraction and presumably of volume per beat while breathing 43 cm. of water positive pressure for periods as long as one-half hour when the subject wore the vest for counter-pressure. However, positive pressures of 29 to 36 cm. of water without the vest for counter-pressure revealed an apparent decrease in size of heart and in the calculated volume per beat; in one experiment the decrease was as great as 30 per cent in calculated minute cardiac output after breathing positive pressure of 36 cm. for five minutes. Further observations will shortly be made with special equipment so that roentgen kymograph records may be obtained in the chamber at altitude

6. Examination of the retinal vessels at ground level show no evidence of venous stasis during positive pressure breathing with the counter-pressure of the jacket for thirty minutes (subject not fatigued) and without the counter-pressure of the jacket for twelve minutes (experiment ended because of fatigue).

7. One experiment on a dog in which the venous pressure, intracranial pressure and arterial pressure were measured while the dog was breathing against pressures which varied between 13 to 52 cm. water while encased in a similarly designed vest for counter-support indicates that under the conditions of the experiment the cerebral circulation was not demonstrably impaired while breathing positive pressure,

8. Arterial blood samples were taken at altitudes up to 50,000 feet breathing under positive pressure in the positive pressure jacket. The data is presented in Table 1 and plotted in Figure 1.

Four arterial blood samples were taken at 50,000 feet during two experiments; the arterial blood oxygen ranged from 92 per cent to 76 per cent saturated, averaging 80 per cent.

The results of ten arterial punctures at 46,000 feet in eight experiments while breathing against 20 cm. of water in the positive pressure jacket show the arterial oxygen saturation (by blood gas analyses) ranged from 87 to 69 per cent, averaging 78 per cent. When the positive pressure was removed at 46,000 feet in three experiments, additional arterial samples were taken within two minutes after pressure was removed; the arterial oxygen saturations then decreased and varied from 72 to 58 per cent, averaging 67 per cent. When the positive pressure was increased to 44 cm. of water in four experiments at 46,000 feet, arterial oxygen saturation ranged from 96 per cent to 88 per cent, averaging 94 per cent.

Arterial carbon dioxide contents and pH's were determined on all blood samples taken at 46,000 and 50,000 feet with 0 cm., 20 cm., and 44 cm. water pressure. pH's ranged from 7.41 to 7.55, averaging 7.47; CO_2's ranged from 39.4 to 48.7 volumes per cent, averaging 43.8 volumes per cent.

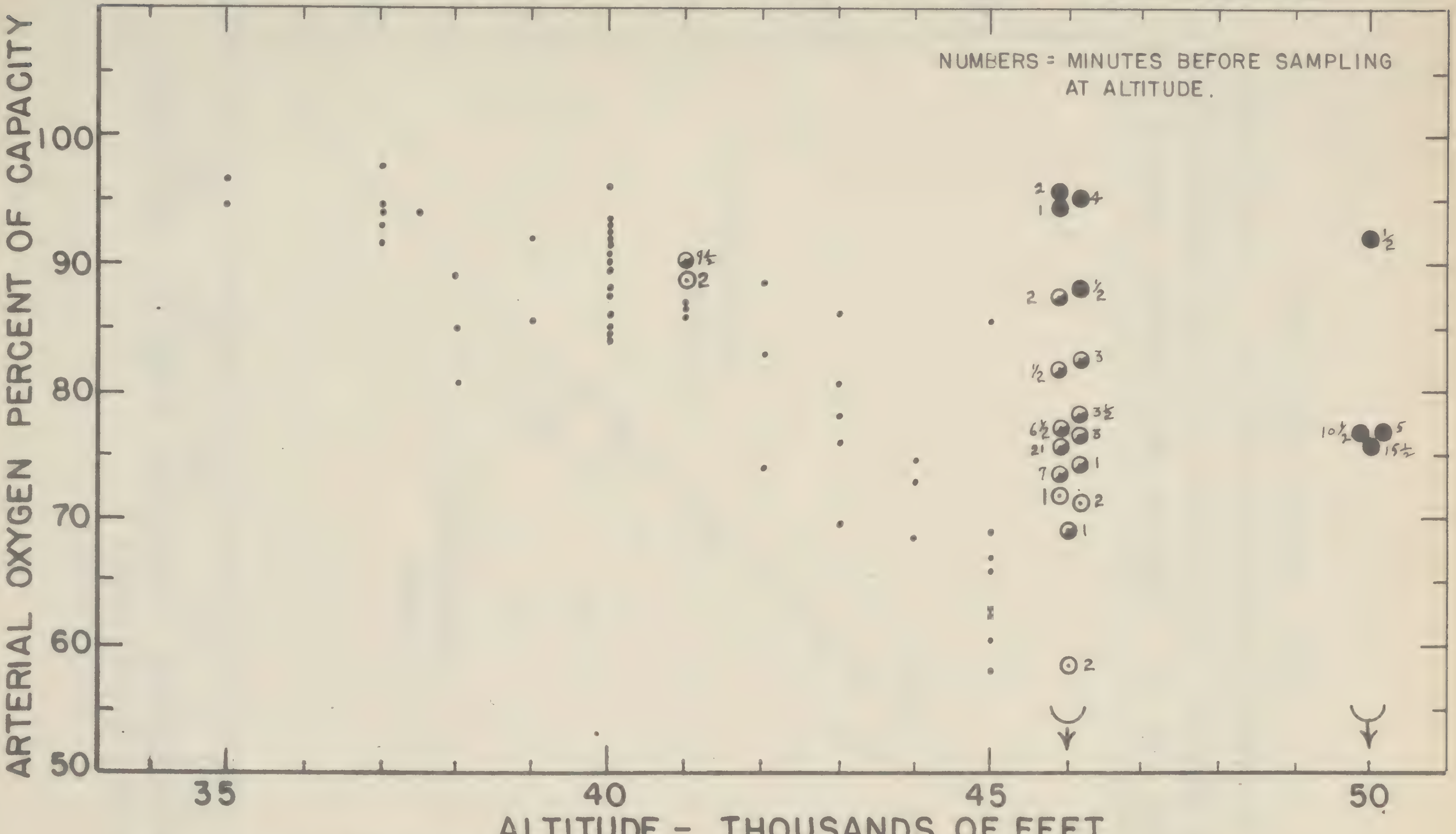
Oximeter readings were carefully taken simultaneously with all arterial punctures. As is shown in Figure II, oximeter readings agreed quite well with arterial oxygen saturations (determined by blood gas analyses) in eighteen samples but did not agree well in five of the samples.

Summary and Conclusion

Counter-pressure by means of a specially designed closed circuit type of rebreathing vest increases the ability of the subject to remain at altitudes from 46,000 to 50,000 feet while breathing against a positive pressure of 30 to 40 cm. of water.

MAYO AERO MEDICAL UNIT

ARTERIAL BLOOD OXYGEN CONTENT BREATHING OXYGEN WITH AND WITHOUT PRESSURE



• No pressure - Physiology of Flight Wright Field, 1940-42, Fig. 8

○ No pressure

◐ 20 cm. water pressure

● 40-46 cm. water pressure

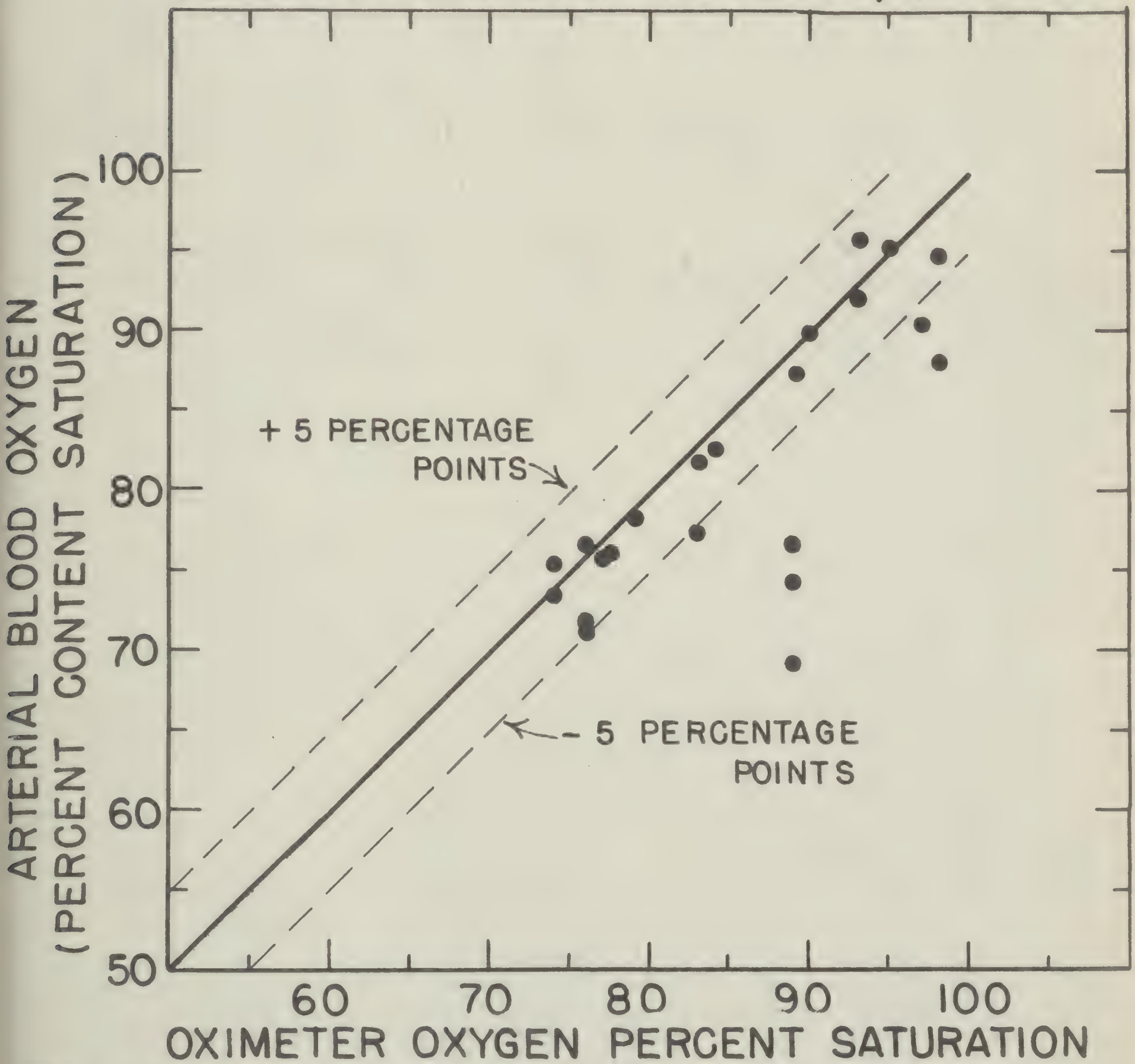
III-8-C

POWER, TAYLOR AND MARBARGER

MARCH, 1943

MAYO AERO MEDICAL UNIT

ARTERIAL BLOOD OXYGEN CONTENT DETERMINATION VS OXIMETER READINGS COLEMAN OXIMETER-MODEL 17, NO. 5769



III - 8 Ca

Power, Taylor, Marbarger
March, 1943

Report No. 4
March 14, 1945

MAYO AERO MEDICAL UNIT

Report to

SUBCOMMITTEE ON OXYGEN AND ANOXIA
NATIONAL RESEARCH COUNCIL

SUMMARY OF RECENT WORK ON RESPIRATION

By

J. B. Bateman
Walter M. Boothby, M.D., Responsible Investigator

1. Drs. Boothby and Helmholz have investigated a suggestion that the sponge rubber discs used in the constant flow oxygen supply system should be replaced by a single orifice. They have compared the pressure-flow characteristics of the two devices. At 28,000 feet for low rates of flow the single orifice offers no measurable resistance while the pressure across the sponge rubber discs is quite appreciable, increasing approximately linearly with rate of flow. It appears therefore that the use of sponge rubber discs is to be preferred from the point of view of oxygen economy.

2. In collaboration with Major Olson of Wright Field, the gas exchange and ventilation rates of normal persons wearing the Burns pneumatic resuscitator has been studied. It was found that after a brief preliminary period of respiratory adjustment, the rate of gas exchange reverts to normal. On the other hand, both ventilation rate per minute and per breath are considerably increased -- a fact which would ordinarily be expected to lead to excessive loss of carbon dioxide. That it does not do so must indicate that the measurements do not indicate the true alveolar ventilation rate, either -- as Fenn has found -- because of a steady flow of gas through the valve or, in part, because of increased respiratory dead space when the intrapulmonary pressure is increased.

Dr. Lundy of the Department of Anesthesiology has found the resuscitator most valuable in cases of respiratory failure under ether or morphine narcosis.

3. Dr. Sheard and I, in a series of experiments under carefully controlled environmental conditions, have studied the changes in skin temperature of the extremities during pressure breathing at ground level and at altitudes. The response is so slight as to be undetectable under any but the most favorable conditions. When free from interference, it seems most typically to consist of an initial slight transient fall of temperature followed by a slow rise of greater magnitude. Reversal may or may not occur upon return to normal breathing. It is clear that the responses observed are not in any way to be interpreted to the detriment of pressure breathing as a desirable procedure at high altitudes.

4. I have obtained preliminary data toward a study of the possible effects of unequal pulmonary ventilation and unequal distribution of blood supply to the lungs of normal individuals. The importance of these factors in the quantitative description of pulmonary efficiency is being considered, and experimental work is being directed toward a closer study of the "average" alveolar air, its variations and the importance of such variations in the

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definition of the diffusion constant of the lung. As a part of the same program, the measurement of residual air is being studied. The open circuit method of nitrogen distribution has given data in agreement with those of Cournand; the independent measurement of residual air by observing the expansion caused by decompression, on the other hand, still offers technical difficulties.

MAYO AERO MEDICAL UNIT

MEMORANDUM REPORT
to
ARMY AIR FORCES MATERIEL COMMAND
Under Contract No. W535ac-25829

SPECIAL REPORT: A

SUBJECT: Accumulated nitrogen elimination at rest and at work.

DATE: November 1940

1. Data

In chart VII-1 are shown the averages of 133 determinations obtained on 17 runs on 2 male subjects on the rate of nitrogen elimination while (A) walking on the treadmill at a rate of 3 miles per hour and (B) sitting in a chair.

2. Chief results

(1) At the end of 150 minutes with exercise the subjects eliminated on the average about 1400 cc.

(2) At the end of 150 minutes without exercise the subjects had eliminated about 950 cc. nitrogen.

(3) When plotted on semi-log paper an asymptote is suggested near a total of 1600 cc.

(4) However when plotted on log-log paper the data fall on nearly straight lines within the time limit of the experiments.

3. Method

(1) The subjects rebreathed through soda-lime into a series of bags previously filled with oxygen.

(2) The final volume was carefully determined by a wet meter.

(3) The amount of nitrogen present was determined by analysis in duplicate on calibrated Haldane gas analyzers by trained technicians.

(4) The amount of nitrogen in the inspired oxygen from the cylinders was also determined by analysis. Proper corrections were made for amount of nitrogen in the correcting tubes and valve.

(5) The general set up of the apparatus is shown as arranged for subject at sitting rest and when walking on the treadmill in Fig. 2.

Prepared by Walter M. Boothby, M.D.

W. Randolph Lovelace, II, M.D.

Otis O. Benson, M. D.

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MAYO AERO MEDICAL UNIT

THE RATE OF NITROGEN ELIMINATION

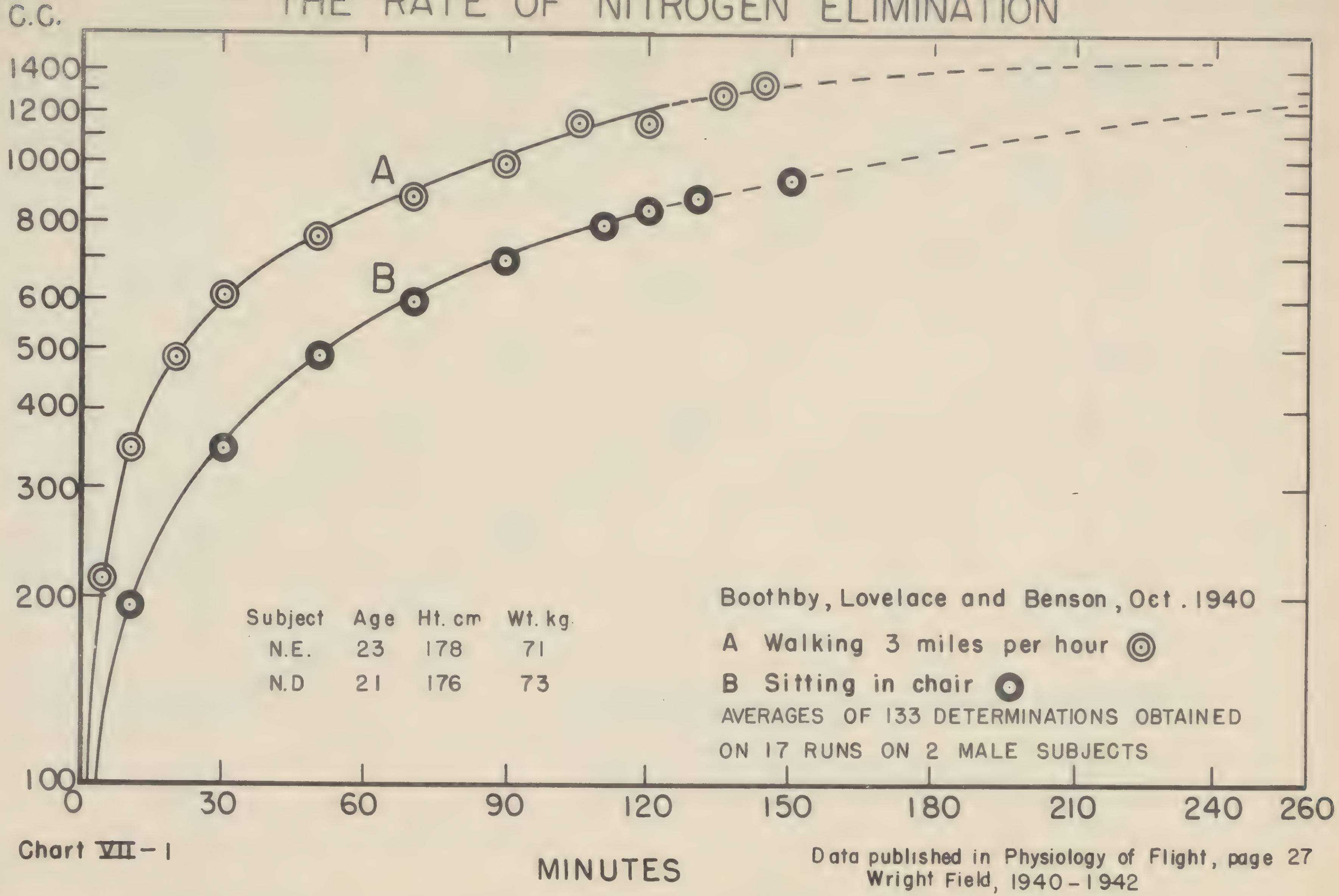


Chart VII-1

Data published in Physiology of Flight, page 27
Wright Field, 1940-1942

THE RATE OF NITROGEN ELIMINATION

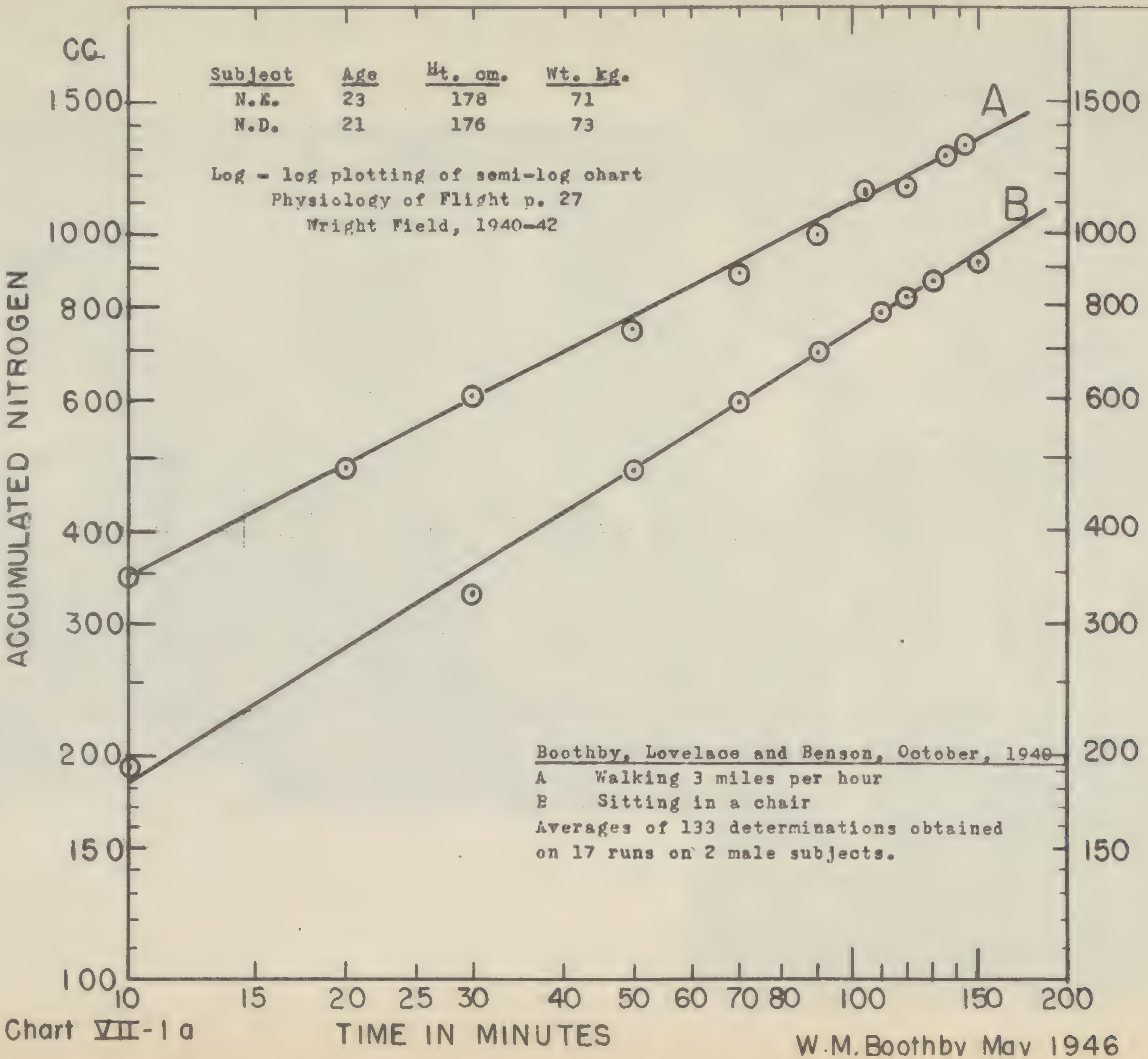


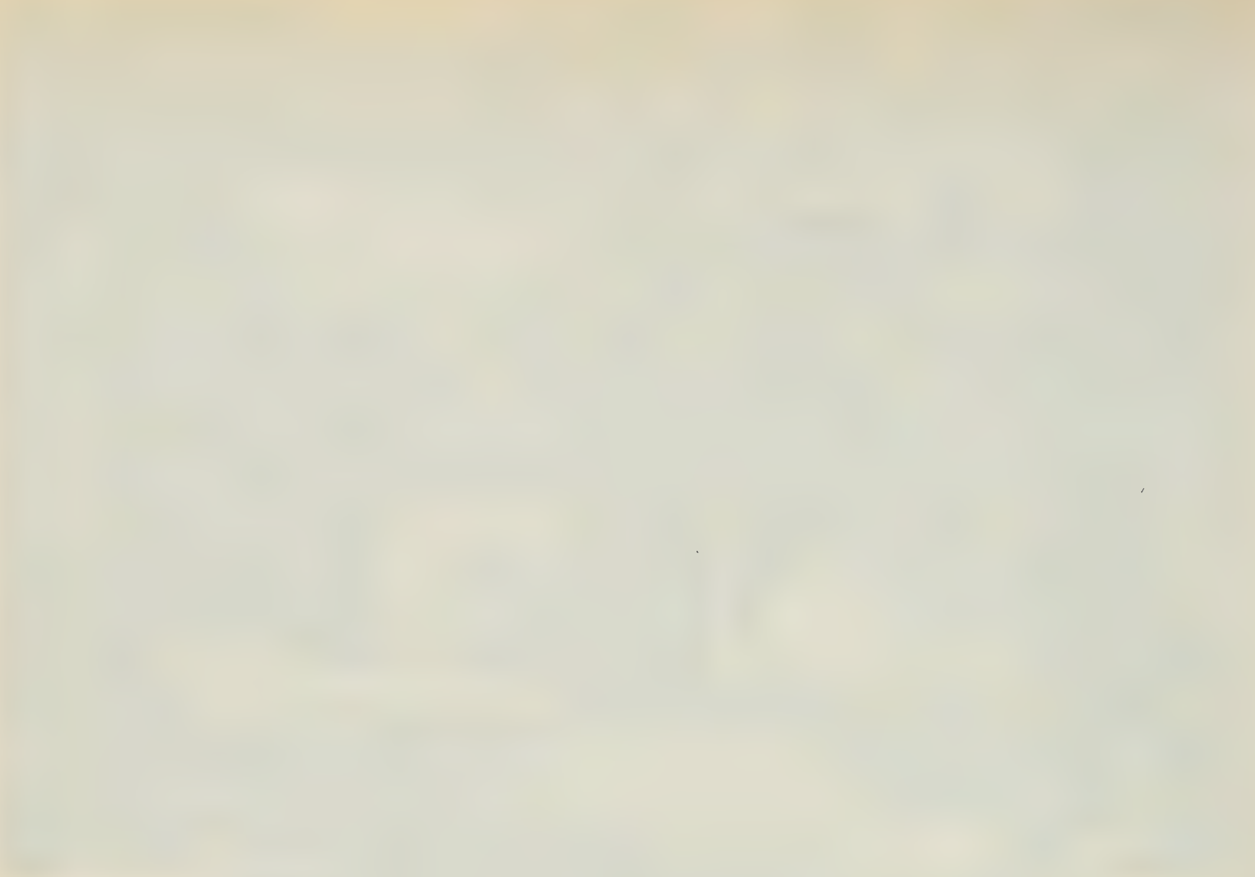
Chart VII-1a

W.M. Boothby May 1946

N_2 ELIMINATION

AT REST

AT WORK



MAYO AERO MEDICAL UNIT

MEMORANDUM REPORT
to
ARMY AIR FORCES MATERIEL COMMAND
Under Contract No. W535ac-25829

SPECIAL REPORT B

DATE: 30 December 1940

SUBJECT: X-ray photographs demonstrating air bubbles in wrist joint at 35,000 feet.

1. Purpose

As Dr. Smedal repeatedly had pains in his wrist joint after a short stay at 35,000 feet, X-ray photographs were taken to determine whether or not air bubbles could be demonstrated as a possible cause of pain.

2. Data

Several x-ray plates were taken at intervals after reaching an altitude of 35,000 feet.

Fig. 2: The photographs taken after 37 minutes at altitude and while still at that altitude showed:

Bone structure normal.

Air bubble visible in ulnocarpal joint space and also in several of the carpocarpal joints.

Fig. 1: The control plate taken immediately after descent to ground level showed:

Bone structure normal.

All gas seen in Figure 2 while subject was at 35,000 feet was no longer visible.

Prepared by: Walter M. Boothby, M. D.

Otis O. Benson, M. D.

Harold A. Smedal, M. D.

Mayo Aero Medical Unit

Fig. I Control
Ground Level, 1000 feet

Fig. 2 Air Bubbles Visible
at Elevation of 35,000 feet

Chart VII A

12-30-40

CONFIDENTIAL

COMMITTEE ON MEDICAL RESEARCH
of the
OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

MAYO AERO MEDICAL UNIT

SPECIAL REPORT NO. 1 CONTRACT NO. OEMcmr-129

DATE August 4, 1942

SUBJECT: The advantages of both the demand and constant flow systems of oxygen administration are combined by the utilization of a small reservoir or economizer bag with the demand type mask.

RESPONSIBLE INVESTIGATOR: Mayo Aero Medical Unit, Walter M. Boothby, Chairman.

AUTHORS: Walter M. Boothby, M.D. presented a laboratory model embodying this new arrangement at the meeting of the Subcommittee on Oxygen and Anoxia in joint session with the Committee on Aviation Medicine of the National Research Council on July 28, 1942.

On a recent visit of Major J. G. Kearby of Wright Field to the Mayo Aero Medical Unit, we discussed, designed and constructed with him a laboratory modification of a demand type "Bulbulian mask" by the addition of a reservoir-rebreathing or economizer bag in such a way that the mask could be used equally well with the constant flow system of oxygen administration or with the demand method.

The reservoir bag permits the use of any type of constant flow or air-oxygen demand type regulator. However, preferably the demand regulator should be modified so that up to 30,000 feet the demand principle is used and above this level a constant oxygen flow of 2.5 liters per minute (STPD), or any other desired amount, comes on automatically by an aneroid; in addition the regulator would have an additional manual control so designed as to give at any altitude an additional constant flow of oxygen of 2.0 or 2.5 liters per minute.

To render possible this combination of oxygen supply methods, ample-sized openings are made in the corrugated tubing about 2 to 3 inches from the mask end. The tube is then passed through a sausage-shaped rubber bag of about 300 cc. effective capacity. The walls of this bag can be heavier than those previously used in the B.L.B. constant flow type of oxygen mask as the corrugated tubing will support the lower end of the bag so that its weight will not interfere with expansion and contraction.

When the straight demand system is used, about 300 cc. of oxygen containing very little carbon dioxide from the first part of the expiration is conserved for rebreathing by expansion of the bag. On inhalation this conserved oxygen is again available as the bag contracts down around the corrugated tube and when empty automatically the negative pressure increases sufficiently to open the demand regulator in the usual manner. If there is a leak, you would still empty the bag.

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The regulator should eventually be so designed that beginning at 30,000 feet a constant oxygen flow of 2.5 liters per minute S.T.P.D. will automatically be turned on by an aneroid. This amount of oxygen is sufficient to produce an outboard leak up to 40,000 feet with the subject at sitting rest. If the aviator starts to work he turns on an additional 2 liters (or 3 liters) which would give sufficient oxygen to produce an outboard leak with the aviator doing as much as 1200 feet pounds of work per minute. If the aviator should inhale an especially deep breath the demand valve would automatically supply the extra amount of oxygen needed.

The rebreathing or economizer bag besides conserving oxygen tends to prevent the washing out of carbon dioxide so that the danger of producing serious symptoms of acapnia is decreased.

The constant flow system at high altitudes with proper rates of oxygen supply gives a constant outboard leak and an average positive pressure in the mask of about 2 cm. water which is a little less than 2 mm. mercury; under these conditions even during inspiration there is no significant negative pressure. At high altitudes (40,000 feet) the average increase in positive pressure will be about $1\frac{1}{2}$ per cent of the total barometric pressure. Gagge has demonstrated a definite increase in the ceiling from slight positive pressure as contrasted to slight negative pressure. One disadvantage of the demand type regulator especially when the subject is working at high altitudes is that during inspiration there is about 2 cm. or more negative pressure with danger of an inboard leak, both causing a lowered ceiling.

The accompanying graphs illustrate the pressure changes produced by inspiration and expiration obtained by a lead off from the microphone cavity inside the mask at rest and at work at different altitudes. These pressures were obtained by an extremely delicate pressure recorder of the spoon type made of thin glass as recently perfected by Baldes. The pressure changes are projected by a mirror onto a centimeter scale or, as here, recorded on photographic paper where 2 cm. of deflection represents 1 cm. water pressure. Graphs 9a, 9b and 9c represent the pressure readings inside the mask when using the constant flow system and graphs 10a, 10b and 10c represent the pressure when using an oxygen demand system. The reproductions are reduced in size.

The demand type mask with reservoir bag thus arranged can be used whether the plane is equipped with the present constant flow regulator or with the new Army demand regulator. The present air-oxygen demand regulator can be easily improved to include both demand and constant flow principles.

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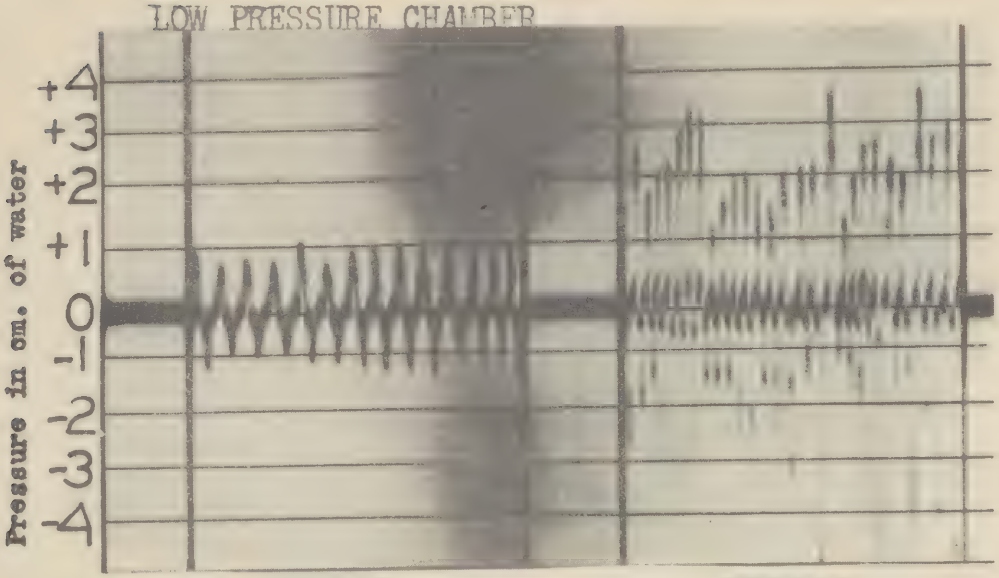
PRESSURE CHANGES IN BLB CHIN TYPE MASK

AT REST AND AT WORK(1200 ft.lbs./min.)

AT VARIOUS SIMULATED ALTITUDES. IN THE

LOW PRESSURE CHAMBER

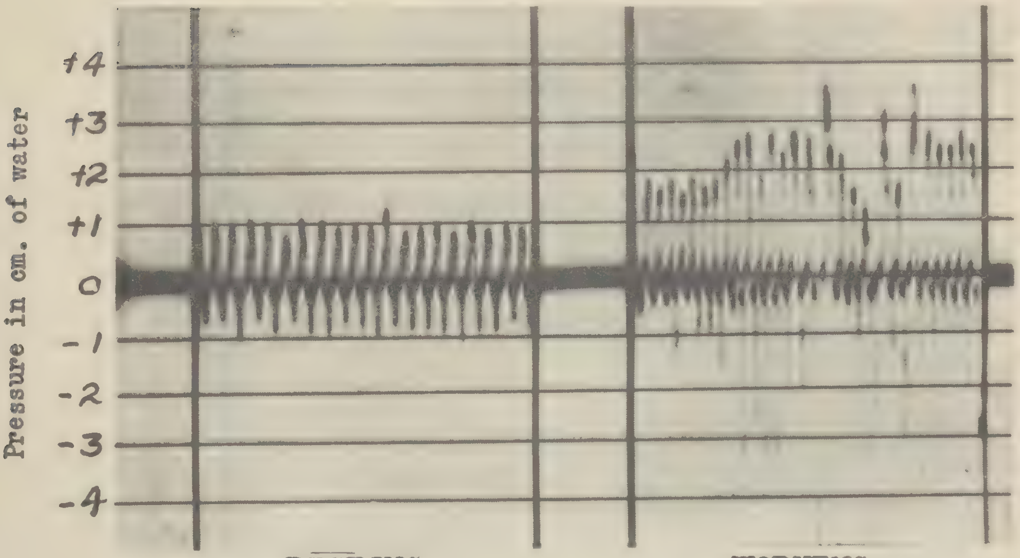


RESTING
FLOW - 0.8 L/min.
- 15,000 Inactive

WORKING
FLOW - 1.6 L/min.
- 15,000 Active

ALTITUDE - 15,000 feet

Mayo Aero-Medical Unit
Boothby, Flinn and Bratt
May 15, 1942



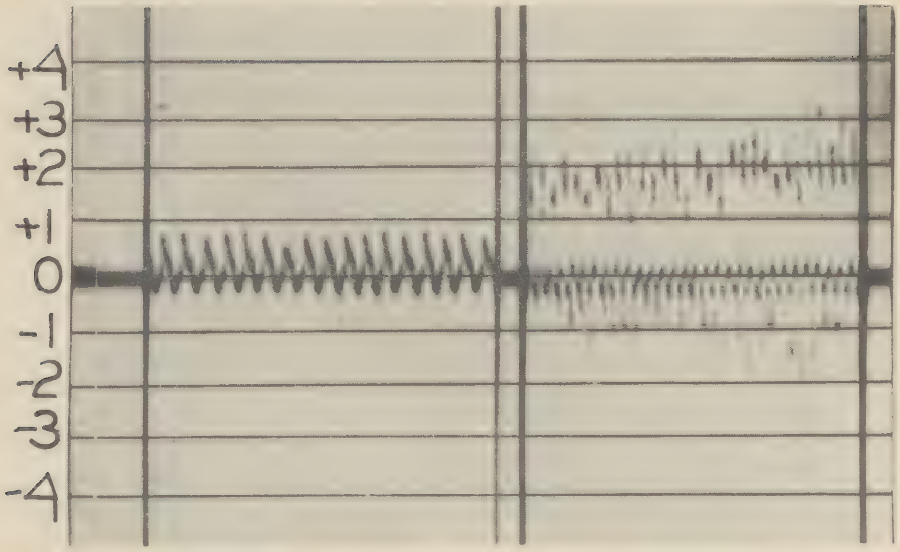
RESTING
FLOW- 1.1 L/min.
- 20,000 Inactive

WORKING
FLOW - 2.1 L/min
- 20,000 Active

ALTITUDE - 20,000 feet

XV 1a

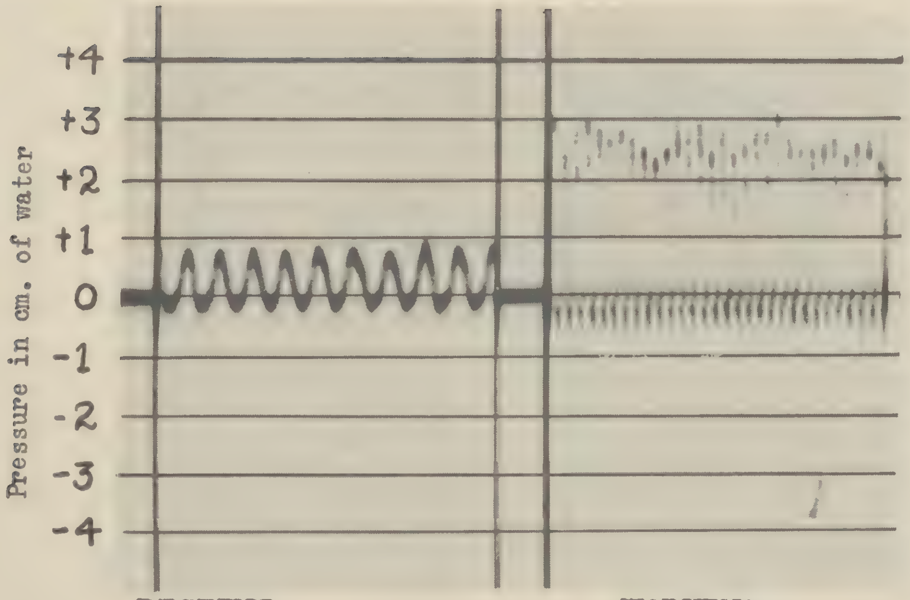
Mayo Aero-Medical Unit
Boothby, Flinn and Bratt
May 15, 1942



RESTING
FLOW - 1.4 L/min
- 25,000 Inactive

WORKING
FLOW - 2.9 L/min
- 25,000 Active

ALTITUDE - 25,000 feet

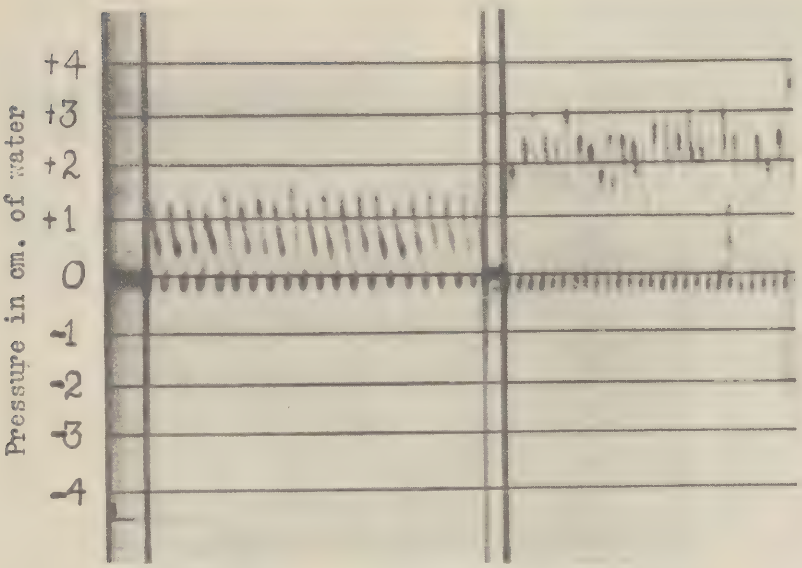


RESTING
FLOW - 1.8 L/min
- 30,000 Inactive

WORKING
FLOW - 3.6 L/min
- 30,000 Active

ALTITUDE - 30,000 feet

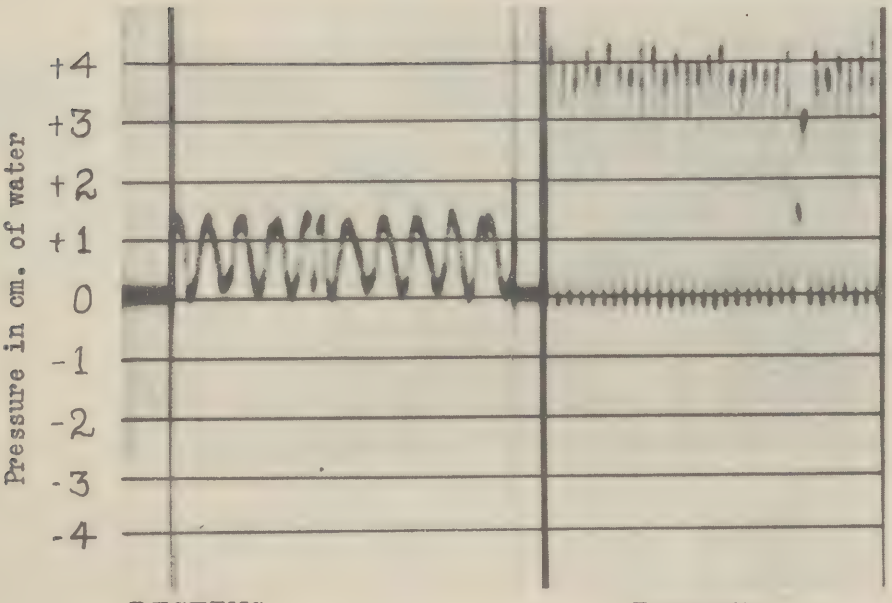
Mayo Aero-Medical Unit
Boothby, Flinn and Bratt
May 15, 1942



RESTING
FLOW - 2.2 L/min
- 35,000 Inactive

WORKING
FLOW - 4.4 L/min
- 35,000 Active

ALTITUDE - 35,000 feet



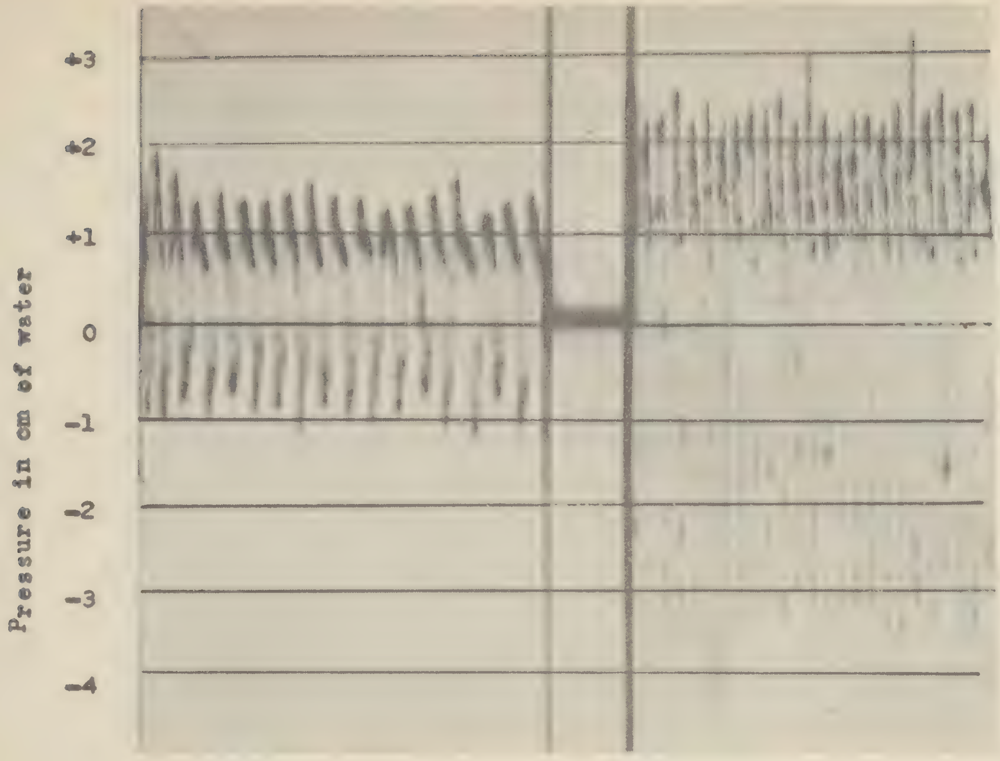
RESTING
FLOW - 2.5 L/min
- 40,000 Inactive

WORKING
FLOW - 5.0 L/min
- 40,000 Active

ALTITUDE - 40,000 feet

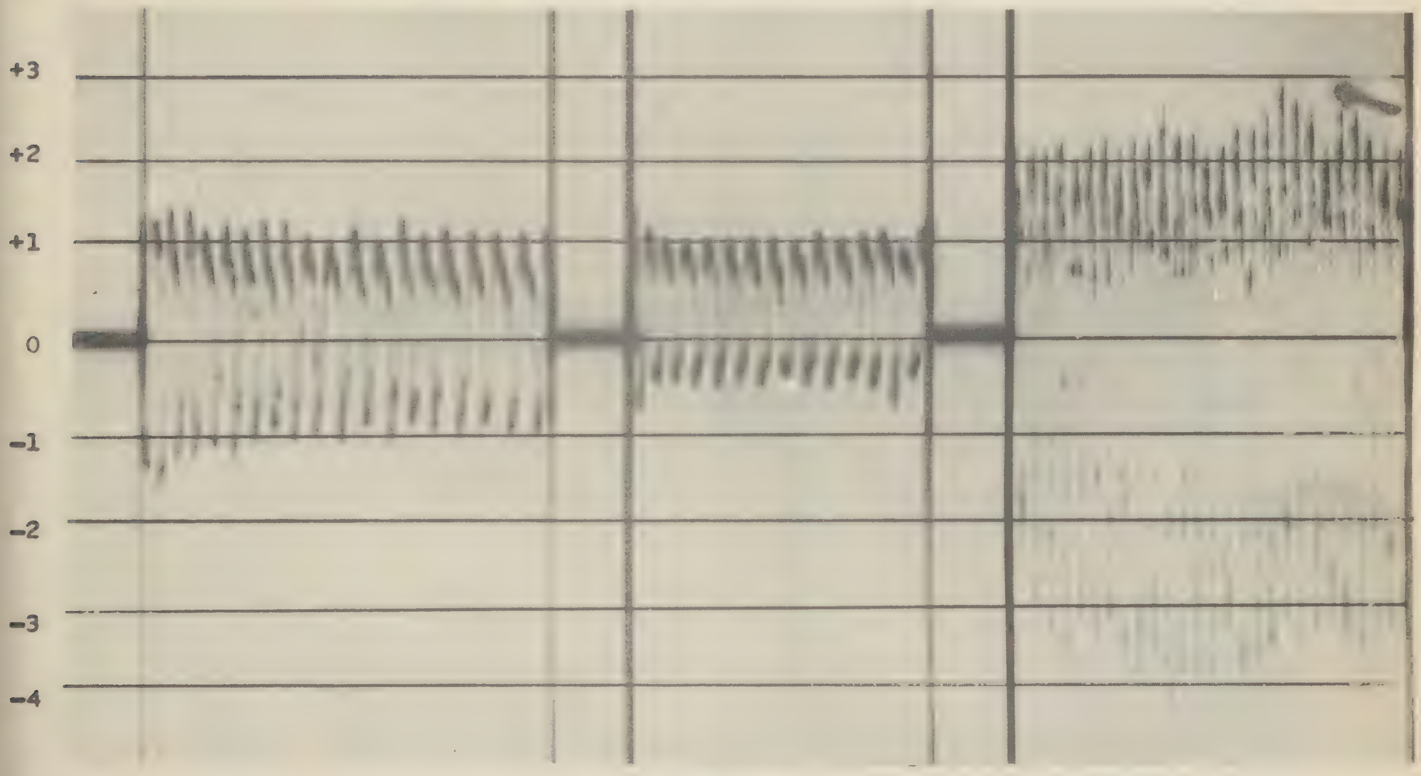
XV 1c-

MAYO AERO-MEDICAL UNIT
ROCHESTER, MINN



RESTING WORKING(1200 ft. lbs/min.

ALTITUDE - 15000 Feet



RESTING

RESTING
(AUTOMATIC REGULATOR
TURNED OFF)

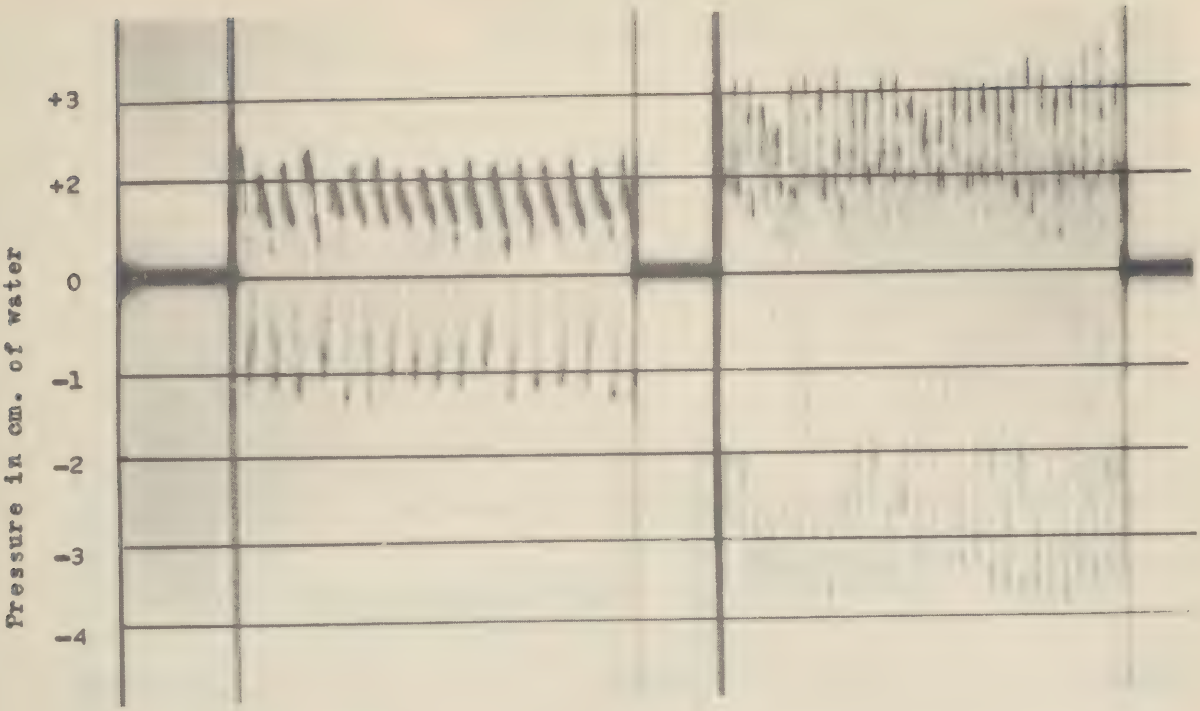
WORKING
(1200 ft. lbs/ min)

JUNE 3, 1942

ALTITUDE - 25000 Feet

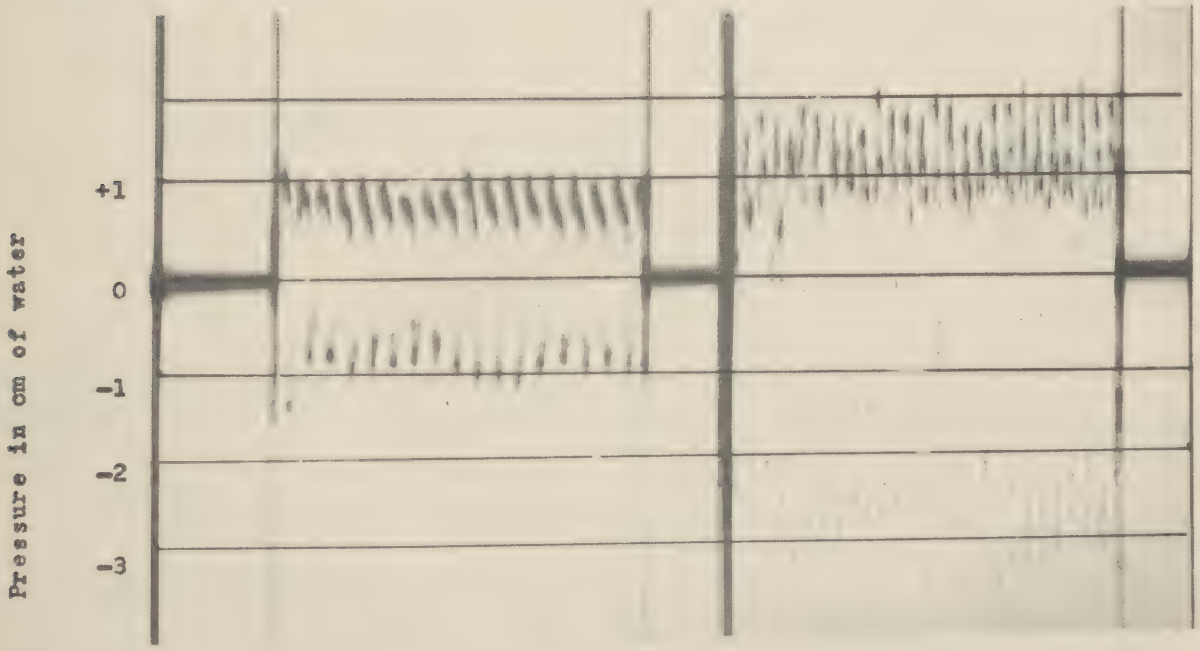
BLB DEMAND ARMY AUTOMATIC REGULATOR TYPE A-12 SERIAL 127 ARO EQUIPMENT CORPORATION

MAYO AERO-MEDICAL UNIT
ROCHESTER MINN.



RESTING WORKING (1200 ft lbs/ min)

ALTITUDE - 30000 Feet



RESTING WORKING 1200 ft. lbs/ min)

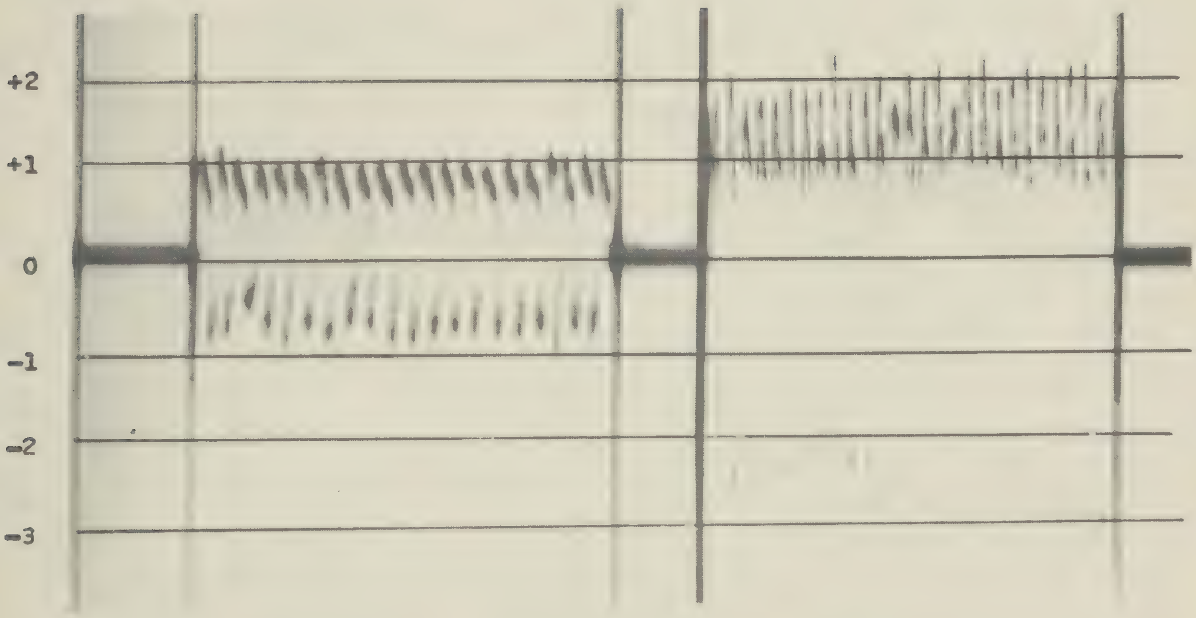
ALTITUDE - 35000 Feet

JUNE 3, 1942

DEMAND ARMY AUTOMATIC REGULATOR TYPE A-12 SERIAL 127 ARO EQUIPMENT CORPORATION

2 b

MAYO AERO - MEDICAL UNIT
ROCHESTER, MINN



RESTING WORKING (1200 ft lbs/ min)

ALTITUDE - 40000 Feet JUNE 3, 1942

BLB DEMAND ARMY AUTOMATIC REGULATOR TYPE A-12 SERIAL 127 ARO EQUIPMENT CORPORATION

XV- 2 c

COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

MAYO AERO MEDICAL UNIT

SPECIAL REPORT NO. 2 CONTRACT NO. OEMcmr-129

DATE 4 August 1942

SUBJECT: Effects of Toxic Doses of Digitalis and of Prolonged Deprivation of Oxygen on the Electrocardiogram, Heart and Brain.

RESPONSIBLE INVESTIGATOR: Mayo Aero-Medical Unit, Walter M. Boothby, M. D., Chairman.

AUTHORS: Dr. W. H. Dearing with supervision of Drs. A.R. Barnes, W.M. Boothby and H.E. Essex.

Studies were designed to determine the effects of prolonged oxygen deprivation on the electrocardiogram, heart and brain of cats. The animals were placed in a large water-sealed chamber and permitted to breathe oxygen at low concentrations for three to eight days. The desired concentration of oxygen (4 to 5 per cent) was attained and maintained by allowing mixtures of oxygen and nitrogen to flow continuously into the chamber. The percentage of oxygen in the chamber was adjusted by controlling the rate of inflow of nitrogen and oxygen through calibrated Heidbrink flowmeters attached to each gas tank. (For example, if the nitrogen flowed at the rate of 9.5 liters per minute and the oxygen at 0.5, then the proportion of oxygen entering the chamber would be approximately 5 per cent). These flowmeter calculations were checked frequently with oxygen determinations made with the Haldane gasometer. The carbon dioxide was prevented from accumulating by maintaining a fairly rapid flow of nitrogen and oxygen through the chamber. The carbon dioxide content varied from .214 to .590 per cent.

The cats seemed to breathe 4 to 5 per cent oxygen without much evidence of distress. When the percentage of oxygen fell too rapidly or was held at too low a level, the animals sometimes showed cyanosis of the nose and tongue, restlessness, drowsiness or panting type of respiration. Death occurred in three animals as a result of respiratory failure (electrocardiograms were taken at the time of death) and three animals were sacrificed in an ether chamber.

At the end of the three to eight day exposure to low oxygen concentrations, electrocardiographic changes in the RST segments and T waves were as follows: (1) decrease or increase of the height of the T wave in one or more leads, usually in all three leads; (2) slight elevation of the RST leads; (3) depression of the RST segment in one or more leads; (4) inversion of the T wave in one or more leads; (5) cove-plane negative T_2 and T_3; (6) negative T_1 and positive T_3. These electrocardiographic changes were altered promptly or reverted to the control pattern when the animals breathed atmospheric air.

Anatomical lesions were found in the myocardium. The earliest lesion consisted of cellular degeneration; subsequently exudative cells appeared in the zones of degeneration. The lesions were focal in distribution and were most prominent in the papillary muscles, left ventricular wall and the interventricular septum. The old animals died sooner and showed more extensive lesions than the young ones. This difference in sensitivity was not due to arterio or arteriolar sclerosis.

Cellular changes were observed in the central nervous system of the three animals examined. The cerebral cortex was most vulnerable to oxygen deprivation. The large and small pyramidal cells showed the following changes: (1) swelling, (2) pyknosis, (3) vacuolization, (4) degeneration (necrosis), and (5) satellitosis. Changes in the cerebellum and pons were minimal. No evidence of degeneration was seen in the spinal cord.

The anatomical changes in the heart and brain and the electrocardiographic alterations appeared comparable to those described elsewhere after toxic doses of digitalis.

Note: This is an abstract of a paper which is the sixth of a series originally planned for determining therapeutic and toxic doses of digitalis. We have withheld this paper from general publication because of its discussion of the effects of oxygen deprivation on the electrocardiogram, heart and brain.

Complete paper sent in to the Subcommittee on Oxygen and Anoxia with this abstract.

EXPERIMENTS WITH CALCULATED THERAPEUTIC AND TOXIC DOSES OF DIGITALIS: VI. COMPARATIVE EFFECTS OF TOXIC DOSES OF DIGITALIS AND OF PROLONGED DEPRIVATION OF OXYGEN ON THE ELECTROCARDIOGRAM, HEART AND BRAIN.*

William H. Dearing, M.D.,
Arlie R. Barnes, M.D.
Division of Medicine,
Walter M. Boothby, M.D.,
Section on Metabolic Investigation, Mayo Clinic,
and
Hiram E. Essex, Ph.D.,
Division of Experimental Medicine,
Mayo Foundation, Rochester, Minnesota

The purpose of this investigation was threefold: (1) to determine whether prolonged deprivation of oxygen would produce electrocardiographic changes which resembled those induced by toxic doses of digitalis; (2) to ascertain whether prolonged deprivation of oxygen was capable of producing histologic changes in the myocardium similar to those observed after administration of toxic doses of digitalis; (3) to find out whether prolonged deprivation of oxygen and toxic doses of digitalis produced similar cellular alterations in the central nervous system.

Literature

The literature on deprivation of oxygen is immense. Much of it, while extremely interesting, is not strictly relevant to our problem. The basic contributions dealing with the effects of deprivation of oxygen on the electrocardiogram, the cellular structure of the myocardium and the central nervous system will be mentioned.

Let us consider first the pertinent publications which describe the changes of the RST segment and the T wave in the electrocardiogram after systemic deprivation of oxygen. Greene and Gilbert[1] reported a decrease of the amplitude of the T wave in the early stages (precrises) of deprivation of oxygen produced in young men during rebreathing experiments; sometimes the T wave was diphasic or negative near the stage of circulatory crisis. Greene and Gilbert[2] made similar observations on dogs. Miki[3] described the "church-spire" T wave of abnormal height in asphyxia. Kountz and Gruber[4] reported that a "high branching T wave" occurred in dogs which were connected with a rebreathing apparatus. This change of the T wave was observed when the oxygen saturation of the blood fell to less than 50 per cent of the normal. These authors concluded that the high branching T wave of coronary occlusion was due to anoxemia. Kountz and Hammouda[5] described changes of the RST segment and the T wave when the right or left coronary artery in the canine heart-lung preparation was perfused with asphyxial blood. These authors concluded that the changes of the RT segment after coronary occlusion were due to a high concentration of locally produced metabolites. Rothschild and Kissin[6] induced anoxemia in thirty-eight persons with a rebreathing apparatus. The electrocardiogram in ten persons showed a downward deviation of the ST segment; one person had an upward deviation of the segment. An average of 7.9 per cent oxygen in the inspired air caused ST changes in the controls while an average of 8.4 per cent produced ST deviations in the group suffering from angina pectoris.

* Abridgment of portion of thesis submitted by Dr. Dearing to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Ph.D. in Medicine.

Katz and Hamberger[7] reported a decrease of the height of the T wave and a depression of the ST segment in studies on twenty normal persons who breathed air in which the oxygen was diminished gradually to 7 volumes per cent. Dietrich and Schweigk[8] described in man with deprivativation of oxygen (8 per cent in inhaled air) a depression of RST_1 and RST_2, negative T_2 and T_3, and an elevation of RST_2 and RST_3 associated with a depression of RST_1. Detreich[9] observed in dogs a flattening of the T wave, inversion of the T wave or a depression of the ST segment. He showed that these electrocardiographic changes occurred when the oxygen in the inspired air ranged from 6 to 9 per cent and when the coronary blood flow, as measured by the Rein thermostromuhr, was increased considerably. Cluset, Piery, Ponthus and Milhaud[10] described an elevation of the T wave in dogs in a low pressure chamber. Tigges[11] observed a flattening of the T wave in normal persons in whom hypoxemia had been induced. Larsen[12] administered 9 per cent oxygen to ninety persons in some of whom he found a depression of the ST segment, flattening of the T wave and inversion of the T waves. Borgard[13] reported flattening of the T waves with a transition to negative T waves; finally, the T wave became high and spiked. These studies were done on animals at low atmospheric pressures. Levy, Barach and Bruenn[14] and Levy, Bruenn and Russell[15] described a flattening of the T waves and an occasionally depressed RST segment in persons who inhaled 10 per cent oxygen and 90 per cent nitrogen. May[16] made similar observations on normal persons.

Binet, Strumza and Ordonez observed in dogs that a negative T_2 occurred when 7.36 per cent oxygen was inhaled and an elevation of the RT segment along with a tall T wave appeared when 2.41 or 2.89 per cent oxygen was administered. Scott, Leslie and Mulinos[18,19] subjected cats to atmospheres containing 10 per cent oxygen both before and after the ligation of the left branch of the anterior descending coronary artery. The RST segment did not deviate from its iso-electric position with anoxemia preoperatively. After the coronary artery had been ligated, the RST segment was deviated upward; in time the RST segment returned to the iso-electric position, even though the infarct persisted. When the animals then were subjected to the anoxemia, the RST segment assumed the deviation pattern seen just after the coronary artery had been ligated. Levy, Bruenn and Williams[20] stated that among patients suffering from angina pectoris and coronary sclerosis changes of the RST segment and the T wave developed after administration of digitalis (1.5 gm. in four days). These changes resembled those seen after anoxemia[14,15]. On the fifth day anoxemia was produced in these digitalized patients; it was found that the deviation of the RST segment diminished by 40 per cent and the interval between the production of anoxemia and the time of appearance of the pain was shortened 9 per cent. The latter observation agrees with the contention of Gilbert and Fenn[21] that digitalis increases the susceptibility of the pain of patients suffering from angina pectoris. Gold, Otto, Kwit and Satchell,[22] on the contrary, stated that the likelihood that digitalis will produce angina is negligible.

Concerning the effects of systemic anoxia on the anatomic structure of the heart several references were found in the literature. Schrötter[23] observed fatty degeneration in the myocardium of guinea-pigs which were subjected to low atmospheric pressures of 230 mm. of mercury for forty hours. Campbell[24] also noted fatty changes in the myocardium of cats, rabbits, cavies and mice after they have been exposed for a long time to low oxygen pressures. Luft[25] observed necrosis in the papillary muscle and in the left ventricular wall of the heart of guinea-pigs which had been subjected to low pressures (230 to 300 mm. of mercury for 120 to 180 hours). For the sake of completeness, it may be worthwhile to mention that Büchner[26] produced necrosis of the myocardium in anemic exercised rabbits and that Liebman[27],

Herzog[28], Gey[29], Gurich[30], Tesseraux[31], Kroetz[32], Nagel[33] and many others have described myocardial degeneration in man after poisoning by illuminating gas. Although the myocardial lesions produced by either coronary occlusion in man or coronary ligation in animals are too familiar to warrant comment, it might be of interest to point out that Tennant, Grayzel, Sutherland and Stringer[34] did not observe anatomic changes in the myocardium until eight hours or more after coronary ligation. Karsner and Dwyer[35] described histologic changes twelve hours after permanent ligation of the coronary artery.

Let us now review some of the major contributions on the effects of deprivation of oxygen on the central nervous system. Deprivation of oxygen has been produced in the central nervous system by temporary ligation of blood vessels, by the use of low pressure chambers and by the inhalation of air of low oxygen content. De Buck and de Moor[36], Mott[37,38], Hill and Mott[39], Gomez and Pike[40], and Gildea and Cobb[41] described cellular changes of the central nervous system after ligation of blood vessels. The changes of the nerve cells consisted of chromatolysis, swelling of the cells, shrinkage of the cells, vacuolization of the cytoplasm, neuronophagia and complete disintegration of the cells. Gildea and Cobb described foci or necrosis in the brains of their cats after temporary ligation of the cerebral vessels; they found that ten minutes of cerebral ischemia was sufficient to impair cortical cells permanently. Martin, Loevenhart and Bunting[42] exposed rabbits to low oxygen tension (average oxygen percentage = 7.21 to 7.98) for twelve to 231 hours. They did not find any anatomic changes in the brain or spinal cord. Ford[43] asphyxiated cats and kittens by washing the air from a bell jar with nitrogen; then the animals were resuscitated and finally killed. No lesions were found in the brain. Büchner and Luft[44] described degenerative changes in the brains of guinea-pigs which were subjected to low atmospheric pressures (250 to 300 mm. of mercury) from 103 to 133½ hours.

Methods

Six cats were used in these studies on deprivation of oxygen. The animals were placed in a large water-sealed chamber (fig. 1) and breathed oxygen at low concentrations for several days. The desired concentration of oxygen was attained and maintained by allowing mixtures of oxygen and nitrogen to flow continuously into the upper portion of one end of the chamber and to flow out through the lower portion of the opposite end of the chamber. The possible influx of atmospheric air into the chamber was prevented by attaching a rubber tube, 6 feet (183 cm.) long end of small caliber, to the outflow opening.

The percentage of oxygen in the chamber was adjusted by controlling the rate of inflow of the nitrogen and the oxygen through calibrated Heidbrink flowmeters attached to each gas tank. For example, if the nitrogen flowed at the rate of 9.5 liters per minute and the oxygen at 0.5 liters per minute, then the proportion of oxygen entering the chamber would be approximately 5 per cent ($\frac{0.5}{9.5 + 0.5} = 0.05$ or 5 per cent). These calculations permitted one to estimate quickly the percentage of oxygen at any moment during the experiment.

Samples of gas were collected at various intervals through a side tube placed near the outflow opening of the chamber. The percentages of oxygen and carbon dioxide were determined in these samples with the Haldane gasometer.

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The percentage of oxygen in the samples [illegible]

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The percentages of oxygen as calculated from the rates of flow of nitrogen and oxygen through the flowmeters agreed fairly well with those determined with the Haldane gasometer. The carbon dioxide was prevented from accumulating by maintaining a fairly rapid flow of nitrogen and oxygen through the chamber; therefore the absorption of the carbon dioxide with soda lime was not necessary. The content of carbon dioxide in the chamber varied from 0.214 to 0.590 per cent.

The cats lay on the right side while electrocardiograms were made at various intervals throughout the course of the experiment. The electrocardiographic lead wires traversed the outflow tube described previously.

The cats were removed from the chamber for a short time each morning to permit cleaning of the chamber, feeding of the animals and readjustment of the electrocardiographic electrodes on their extremities. The electrocardiograms were taken as described elsewhere[45].

Notes were made on the appearance and behavior of the animals while they inhaled the gas mixture poor in oxygen.

The animals which did not die spontaneously were killed in an ether or chloroform chamber after they had inhaled the mixtures poor in oxygen for three to eight days. The heart, brain, spinal cord, stomach, duodenum, ileum, uterus, biceps, diaphragm and abdominal musculature were prepared for microscopic study in accordance with the procedure described in a previous paper[46].

The control animals for the microscopic studies were the same as those described elsewhere[46].

Results

A. Anatomic studies of the myocardium after prolonged systemic deprivation of oxygen.- It will be recalled that the myocardium of the control animals did not reveal any evidence of degenerative change.

Table 1 indicates the effects of prolonged systemic deprivation of oxygen on the myocardium in our experimental animals. There were no changes in the myocardium of the animal which died one and a half hours after the inhalation of low concentrations of oxygen, while the five animals which survived three or more days in the gas mixture poor in oxygen exhibited varying degrees of histologic change in the myocardium.

The anatomic lesions produced in the myocardium after prolonged exposure to low oxygen tensions differed very little from those seen after injection of toxic doses of digitalis (compare fig. 2 with fig. 1 of the first paper of this series).[46] The lesions produced by digitalis were, as a rule, more extensive than those seen after deprivation of oxygen. The earliest definite and obvious change in the myocardium after prolonged anoxia was degeneration of the muscle fibers in localized zones (fig. 2). In time cellular degeneration plus exudative cells was present in the myocardium. These histologic changes were apparently not different from those seen after administration of digitalis or pitressin, coronary ligation and so forth.

The cellular changes were most prominent and extensive in the papillary muscle, the left ventricular wall and the interventricular septal wall. Except in two animals the atrial and auricular anatomic changes were either absent or difficult to recognize.

The old animals died sooner and showed more extensive myocardial lesions than the young ones. For example, an old cat died spontaneously after three days of deprivation of oxygen and its heart contained extensive degenerative changes, while a young adult cat lived for eight days at low oxygen tensions, was killed on the eighth day and its heart showed only a few degenerative lesions. This difference of sensitivity to deprivation of oxygen was not based on arteriosclerosis in the older animal, for no evidence of this disease was observed in the coronary arteries or arterioles of any of our experimental animals.

B. Electrocardiographic studies during prolonged systemic deprivation of oxygen.- The changes of the RST segment and the T wave observed after deprivation of oxygen (table 2) were as follows: (1) decrease of the height of the T wave in one or more leads, usually in all three leads; (2) increase of the height of the T wave in one or more leads; (3) inversion of the T wave in one, two or three leads; (4) depression of the RST segment in one or more leads; (5) cove-plane negative T_2 and T_3; (6) negative T_1 and positive T_3.

The RST segment was not elevated significantly (plateau type) in any of the electrocardiographic tracings made while the animals were inhaling gas mixtures poor in oxygen. It is not known whether the segments would have become elevated if the animals had been permitted to remain out of the low oxygen chamber for a day or so after myocardial lesions had developed.

The succession of electrocardiographic changes usually was initiated by decreases of height of the T waves and sometimes by a negative T_3; then either tall T waves or simple inverted T waves in one or more leads were observed; depression of the RST segments with diphasic T waves in one or more leads (fig. 3) was noted to precede or follow the tall T waves or the simple inverted T waves; finally cove-plane negative T_2 and T_3 with flattened T_1 and diphasic T_1 preceded by a depressed RST_1 segment were observed (fig. 4). When the animals were permitted to breathe atmospheric air, the foregoing electrocardiographic changes were altered promptly or reverted to the normal pattern.

Many other electrocardiographic changes were observed during the various grades of anoxia; sinus tachycardia, sinus bradycardia, prolongation of the QT interval, heart block, decreased height of QRS complex, flattening of P wave and so forth.

C. Anatomic studies of the brain and spinal cord after prolonged systemic deprivation of oxygen.- The central nervous system of only three of our six experimental animals was examined microscopically (table 3). The cerebral cortex (frontal, motor and visual), the cerebellum, the pons and the spinal cord (cervical, thoracic and lumbar) were the portions of the nervous system studied. The cerebral cortex was the most vulnerable to deprivation of oxygen. Degenerative lesions were observed in the cortices of all three animals. The cerebellum of one animal showed a few pyknotic and vacuolated cells. The pons in two animals contained scattered pyknotic and vacuolated cells. No evidence of degeneration was seen in any of the cells in the spinal cord.

The type of changes observed in the large and small pyramidal cells of the cerebral cortex may be summarized as follows: (1) swelling; (2) pyknosis; (3) vacuolization; (4) degeneration (necrosis), and (5) satellitosis.

The cellular changes are essentially the same as those described after digitalis had been administered in toxic amounts. The lesions produced by digitalis were far more extensive and intensive than those produced by deprivation of oxygen. Figure 5 illustrates the degenerative changes in the pyramidal cells after prolonged deprivation of oxygen.

D. Signs observed in animals while they were subjected to systemic deprivation of oxygen.- An endeavor was made to keep the percentage of oxygen in the chamber at a level which produced only slight drowsiness in the animals. The cats seemed to breathe 4 to 5 per cent oxygen without much evidence of distress. When the percentage of oxygen fell too rapidly or was held at too low a level, the animals became restless and exhibited a panting type of respiration.

Sometimes cyanosis of the tip of the nose and tongue was observed. Vomiting occurred on two occasions. Ataxia was noted in several of the animals when they were removed from the chamber for the daily feeding. This ataxia did not persist very long. Death occurred as the result of respiratory failure in three cats; electrocardiograms were taken on these three animals when death occurred - the respirations ceased before the heart stopped beating.

At any given low percentage of oxygen the old animals showed more tendency to cyanosis and panting respiration than did the young animals. The old cats died sooner than the young ones while breathing the same percentage of oxygen.

Comment

The experimental methods used in these studies were simple and readily controlled. The percentage of oxygen was checked by two independent methods. The necropsies were done immediately after the animals died or were killed. The myocardial and cerebral degenerative changes had to be definite before we counted them as myocardial or cerebral lesions. This avoided quibbling about borderline intracellular morphologic changes.

In order to avoid errors in the interpretation of these experimental results, it should be pointed out that these animals were subjected to rather severe grades of anoxia over long periods. We do not know how the cat and man compare in their relative sensitization to deprivation of oxygen. We wish to avoid the interpretation that, just because the electrocardiographic, myocardial and cerebral changes after prolonged deprivation of oxygen resemble those seen after administration of toxic doses of digitalis, the lesions produced by digitalis are therefore the result of anoxia and nothing else. This conclusion is unwarranted. The fact that the deprivation of oxygen may produce changes similar to those induced by toxic doses of digitalis may be interpreted as possible presumptive evidence, but certainly not as direct proof, that anoxemia may be one of the many factors involved in the production of the myocardial and cerebral lesions after administration of digitalis.

In order to avoid another error of interpretation, it may be worthwhile to emphasize that existing experiments of short duration (done by others) indicate that anoxia dilates the coronary arteries and increases the coronary blood flow.

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Summary

Histologic changes were observed in the myocardium of animals which were subjected to prolonged systemic deprivation of oxygen over periods of three or more days. An endeavor was made to keep the concentration of oxygen near to 4 to 5 per cent. One animal which died one and a half hours after the inhalation of low percentages of oxygen did not show any evidence of anatomic changes in the myocardium.

The myocardial lesions produced by deprivation of oxygen resembled those described in the heart after administration of toxic doses of digitalis. They were focal in distribution and were most prominent in the papillary muscle and in the left ventricular wall.

The following is a summary of the prominent changes of the RST segment and the T wave after prolonged systemic deprivation of oxygen (1) decrease or increase of the height of the T waves in one or more leads, (2) simple inversion of the T waves in one or more leads, (3) depression of the RST segment in one or more leads, (4) cove-plane negative T_2 and T_3, and (5) negative T_1 and positive T_3.

The electrocardiographic changes, as a rule, disappeared when atmospheric air was introduced into the chamber.

Cellular changes were observed in the central nervous system after prolonged deprivation of oxygen. The changes were similar to those described by others after anoxia and to those observed after administration of toxic doses of digitalis.

Old animals were more sensitive to deprivation of oxygen than young ones.

Addendum

These investigations were done in 1938 and were presented at a meeting of the Rsearch Club of the Mayo Foundation in December, 1940. Investigations subsequent to the latter date were not included in this paper, therefore, the work on "The Recovery of Function Following Arrest of the Brain Circulation" by Herman Kabat, Clarence Dennis and A. B. Baker and similar recent articles have not been included.

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Legends*

Fig. 1. Diagram illustrating the apparatus used to attain low percentages of oxygen over long periods (days). a. Water-sealed chamber with wire cage floor; b, cross section showing the structure of the water-sealed border of the chamber; c, tube through which the gas mixture flowed into the chamber; d, tube, 6 feet (183 cm.) long, through which the gas mixture flowed from the chamber; e, side tube through which samples of gas were collected; f, sealed glass jar in which urine was collected; g, Heidbrink flowmeters connected to the oxygen and nitrogen tanks.

Fig. 2. Degenerative changes in the myocardium after prolonged systemic deprivation of oxygen (x450).

Fig. 3. On the left, control electrocardiogram; on the right, depression of the RST segment after systemic deprivation of oxygen.

Fig. 4. On the left, control electrocardiogram; on the right, cove-plane negative T_2 and T_3 after prolonged deprivation of oxygen. Myocardial lesions were associated with this pattern.

Fig. 5. Degeneration of the pyramidal cells of the cerebral cortex after prolonged deprivation of oxygen (x450).

* Figures published in Amer. Heart Jour. Vol.27: 108-120, Jan. 1944

Table 1

Correlation of duration of the systemic deprivation of oxygen and the histologic studies of the myocardium

Av. O_2 %	Minimal O_2 %	Duration of exp.	Histologic changes: Papillary muscle and left ventricle	Interventricular septum	Right ventricle	Left atrium	Right atrium	Remarks
4.43	4.43	1½ hr.	No	No	No	No	No	Died
4.54	4.36	3 days	Yes++++	Yes++++	Yes++	Yes+	Yes+	Extensive lesions
4.82	3.54	4 days	Yes++	Yes++	Yes+	?	?	Extensive lesions
5.29	4.36	4 days	Yes+	Yes+	Yes+	?	±	Extensive lesions
4.86	4.58	5 days	Yes+++	Yes++	Yes+	Yes+	Yes+	Moderately extensive lesion
4.71	4.36	8 days	Yes+	Yes+	Yes±	No	No	Few lesions

Table 2

Correlation of the duration of systemic deprivation of oxygen, the histologic studies of the myocardium and the most prominent change of RST segment and T wave observed during the experiment

Average oxygen, per cent	Minimal oxygen, per cent	Duration of experiment	Histologic change in myocardium	Most prominent change of RST segment and T wave observed
4.43	4.43	$1\frac{1}{2}$ hours	No	Negative T_1
4.54	4.36	3 days	Yes	Cove-plane negative T_2 and T_3; T_1 flattened but positive
4.82	3.54	4 days	Yes	Depression RST_1, RST_2 and RST_3; finally cove-plane negative T_2 and T_3
4.86	4.58	5 days	Yes	Depression RST_1, RST_2 and RST_3; finally cove-plane negative T_2, and T_3
4.71	4.36	8 days	Yes	Depression RST_1, RST_2 and RST_3

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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 3

Correlation of the duration of systemic deprivation of oxygen and the studies on the cellular structure of the central nervous system

Average oxygen, per cent	Minimal oxygen, per cent	Duration of experiment	Histologic changes				Remarks
			Cerebrum	Cerebellum	Pons	Spinal cord	
4.43	4.43	1½ hrs.	--	--	--	--	Died
4.54	4.36	3 days	--	--	--	--	Died
4.82	3.54	4 days	Yes+++	±	±	No	Extensive lesions
5.29	4.36	4 days	--	--	--	--	Died
4.86	4.58	5 days	Yes+++	No	±	No	Moderately extensive lesions
4.71	4.36	8 days	Yes+±	No	No	No	Few lesions

CONFIDENTIAL

No. 14

COMMITTEE ON MEDICAL RESEARCH
of the
OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

MAYO AERO MEDICAL UNIT

SPECIAL REPORT NO. 3 CONTRACT NO. OEMcmr-129

DATE Aug. 20, 1942

SUBJECT: Development of oxygen equipment: Physiological criteria to be considered by engineers.

RESPONSIBLE INVESTIGATOR: Mayo Aero Medical Unit, Walter M. Boothby, M.D., Chairman.

AUTHORS: Walter M. Boothby, M. D., checked by E. J. Baldes, Ph. D.; written in response to a request by Lt. Commander L. D. Carson, (MC) USN, through Dr. L. B. Flexner, Technical Aide to the Committee on Aviation Medicine of the National Research Council.

I. The partial pressure of oxygen expressed on the percentage basis required for delivery to the face for inhalation at altitudes from 10,000 to 40,000 feet.

The amounts required are based on a series of calculations, the results of which are presented in the following series of charts.*

CHART I

Curve 1. This curve represents the total atmospheric pressure at various altitudes based on the standard atmosphere charts of the National Advisory Committee for Aeronautics, Report No. 538, September 1935.
Curve 2. This curve represents the partial pressure of oxygen in dry atmospheric air and is obtained by multiplying the total atmospheric pressure as shown in curve 1 by 0.209, the fractional part of oxygen (20.93 per cent rounded off to 3 significant figures) in dry atmospheric air. This calculation assumes that the atmospheric pressure in curve 1 represents dry air. The fact that this is not necessarily true does not invalidate the calculations as will be seen in the following chart.

CHART II

Curve 2. This curve represents the oxygen pressure of dry atmospheric air and is the same as curve 2 in Chart I.
Curve 3. Represents the factors for reducing the partial pressure of dry gases by saturating them with water vapor at an average body temperature of 37° C. The vapor pressure of distilled water at 37° C is 47.1 mm. Hg. Physiologists, by nearly universal consent, have accepted 47 mm. Hg as the average pressure of the water vapor in the lungs and in body tissues generally. In certain cases it is possible that the vapor pressure of tissue fluid may be two or three millimeters lower than that of pure water; it would also vary with body temperature. However, as an average value it can be used in aviation problems without causing any significant error in the calculated results.

*We are indebted to Major Joseph Berkson, (MC) of the Air Surgeon's Office for assistance in the elucidation of this problem. Before going on active duty Major Berkson helped in the calculations and in the construction of the charts so that the physiological factors and physical factors involved could be presented diagrammatically as an aid to engineers.

On the right-hand side of Chart II are diagrams to illustrate the reason for the correction factor $\frac{B - 47}{B}$ for water vapor. The validity of using this factor for correcting for water vapor need not be elaborated here as it is the method accepted by all competent authorities.

Curve 4. The oxygen pressure in the tracheal air is obtained by multiplying the values of curve 2 by $\frac{B - 47}{B}$ using the factors given in curve 3.

"Tracheal air" is a convenient term to designate atmospheric air which has been saturated with 47 mm. water vapor corresponding to an average body temperature of 37° C. The meaning is not restricted in an anatomical sense but the term is used to avoid the necessity of repeating the long phrase, "air as it is inhaled into lungs saturated with moisture at 37° C. before gaseous exchange has taken place."

Curve 5. After air enters the lungs the oxygen is absorbed therefrom and carbon dioxide is given off. On the average the decrease in oxygen pressure has been found to be between 40 and 50 mm. less than the oxygen pressure in the inspired tracheal air saturated with water vapor as will be shown experimentally in Charts 4 and 5. In the grand average this decrease is 45 mm. However, as under certain conditions the decrease is only 40 mm. we have used this value in the simpler calculation in order to be on the safe side in calculating the amount of oxygen that should be delivered to the aviator. In this presentation we are not concerned with the method of calculating nor with some slight variations in the level of the alveolar oxygen pressure under different conditions as shown in Charts 4 and 5, but rather with the fact that under varying conditions the alveolar oxygen pressure is on the average a very predictable value within quite narrow limits; furthermore, we consider it axiomatic that if the partial pressure of oxygen be maintained normal in the inspired tracheal air, then the alveolar oxygen will also be maintained normal.

CHART III

Curve 1. This curve shows the oxygen pressure of tracheal air being maintained normal at 149 mm. up to 33,000 feet. Above this level even when the aviator is being provided with pure oxygen he can no longer maintain a normal oxygen pressure in the tracheal air and above this level there will be a rapid decrease in total oxygen pressure delivered to the mask and therefore the alveolar oxygen pressure will decrease. Pure oxygen must always be supplied above 33,000 feet. To be sure of this automatic aneroid air-oxygen demand valves are usually set to give only pure oxygen above 30,000 feet.

Curve 2. However, to maintain a normal partial pressure of 149 mm. in the tracheal air with increasing altitude up to 33,000 feet, the dry atmospheric mixture must have a higher and higher partial pressure of oxygen because as the altitude increases the influence of subtracting 47 mm. water vapor from the barometric pressure in the denominator of the fraction $\frac{B}{B - 47}$ becomes greater. This factor is the reciprocal of the factor given in curve 3 of Chart II.

Curve 3. This curve converts the partial pressure of oxygen in the inspired dry mixture of curve 2 to a percentage basis. It is obtained by dividing the values of curve 2 by the barometric pressure and multiplying by 100.

The values in curve 3 are the per cent of oxygen (including that in the air as well as the oxygen added from the tank) that must be present in the inspired mixture (both expressed on the same basis either wet or dry) to maintain oxygen pressure normal at 149 mm. in the tracheal air, and in consequence maintain the alveolar oxygen pressure normal. This data is of considerable value for physiologists.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Curve 4 of Chart III indicates the fraction of a liter of oxygen (Table I) that must be added per liter of ventilation both measured at the ambient barometer and 37° C saturated, that is, per liter of tracheal air. This method of expression is preferred by the physiologist as it represents the actual volume at body conditions. (See Appendix I for method of calculation.)

Curve 5 of Chart III is the same amount of oxygen as shown in curve 4 but the method of expression has been converted to standard temperature and pressure dry (Table I). This is the amount of oxygen measured at 760 mm., 0° C and dry (STPD) which must be added from an oxygen tank for each liter of ventilation, the latter being measured at ambient barometer, 37° C, saturated (tracheal air) to maintain a normal oxygen pressure of 149 mm. in the tracheal air. This method of expression is valuable for the engineer.

In curves 4 and 5 of Chart III are given the values calculated by the formula given in Appendix I. These values expressed as a fraction of a liter of oxygen needed per liter of ventilation are exactly correct to maintain the tracheal inspired air at the normal level of 149 mm. These values for every 5000 feet altitude are charted in part A of Table I.

However, as emphasized by the Aero Medical Research Laboratory at Wright Field, it is by no means necessary always to provide ground level conditions and they have taken as an absolutely minimum oxygen supply the amount necessary to maintain the tracheal oxygen at 117 mm. corresponding to an elevation of approximately 6000 feet, where the barometric pressure is 609 mm. The partial pressure of oxygen in the tracheal air would therefore be 117 mm. instead of 149 mm. calculated as follows: (609 - 47) x .209 = 117 mm. This would produce an alveolar partial pressure of around 70 mm. and this in turn, as shown by Lt. Colonel Dill, would keep the percentage saturation of the hemoglobin in arterial blood at 93 per cent saturation; this is a perfectly satisfactory minimum level for an aviator. The amount of oxygen per liter of ventilation needed to maintain an aviator's tracheal and alveolar oxygen pressure at 117 mm., the equivalent of 6000 feet, are given in part B of Table I. If this minimum value is used one must remember that part of the "Safety Factor" is gone and care must be taken to allow for this in subsequent calculations.

In part C are presented the rates of flow recommended by the Mayo Aero Medical Unit and used by them in the accumulation of data such as that shown in Charts VI and VII. It will be noted that the actual rates of flow recommended and tested by them with the constant flow method of administration at the lower elevations is about half way between the amounts needed to maintain complete normality and those required to maintain the aviator at the equivalent of 6000 feet.

We wish to emphasize once more that the data given in part A of Table I under "Requirement I" is the exact amount of oxygen needed by the aviator per liter of ventilation, the latter measured at lung conditions of ambient barometer, 37° C, and saturated with moisture. The data in part B is the minimum requirement that should be intentionally provided and is the equivalent of holding the aviator at 6000 feet. The data in part C represents an early compromise upon which a lot of actual data has been accumulated by the Mayo Aero Medical Unit.

Table I.

OXYGEN REQUIREMENT FOR AVIATORS

Oxygen requirement for aviators at various altitudes per liter of ventilation: The ventilation is always measured at ambient barometer, 37° C and saturated. The oxygen is measured at (1) ambient barometer, 37° C saturated and at (2) STPD.

Requirement I: The amount of oxygen needed per liter of ventilation to keep the tracheal air and therefore the alveolar air normal as at sea level up to 33,000 feet where pure oxygen must be used. To maintain the alveolar air normal, the oxygen pressure in the tracheal air must be kept at 149 mm.

Requirement II: The amount of oxygen needed per liter of ventilation to maintain the tracheal and therefore the alveolar air as though the aviator were at an elevation of 6000 up to 37,000 feet (36,800 ft.) where pure oxygen must be used. To maintain the alveolar air equivalent to 6000 feet, the oxygen pressure in the tracheal air must be kept at 117 mm.

Altitude in thousands of feet	Barometer	A. Requirement I. Sea level tracheal O_2 = 149 mm. Amount O_2 needed per liter of ventilation at Bar. 37° C Sat. Oxygen measured at		B. Requirement II. 6,000 ft. tracheal O_2 = 117 mm. Amount O_2 needed per liter of ventilation at Bar. 37° C Sat. Oxygen measured at		C. B.L.B. Recommendation per liter of ventilation at Bar. 37° C Sat. Oxygen measured at	
		Bar. 37°C Sat.	STPD	Bar. 37°C Sat.	STPD	Bar. 37°C Sat.	STPD
5	632	0.06	0.04	---	---	---	---
10	523	0.13	0.07	0.05	0.03	0.09	0.05
15	429	0.23	0.10	0.12	0.05	0.18	0.08
20	349	0.36*	0.13	0.23	0.08	0.28	0.10
25	282	0.54	0.15	0.37	0.10	0.51	0.14
30	226	0.79	0.16	0.56	0.12	0.87	0.18
33	196	1.00	0.17	0.73	0.12		
35	179	1.00	0.15	0.80	0.12	1.45**	0.22
37	164	1.00	0.13	1.00	0.13		
40	141	1.00	0.11	1.00	0.11	2.69**	0.25

*For example, for each liter inspired the mixture is composed of 0.36 liters oxygen taken from the tank and 0.64 liters taken from the atmosphere, both measured at Bar. 37° C Sat. The value 0.36 liters is reduced to 0.13 liters when measured at STPD which is the convenient expression for the supply officer to calculate the amount available in his tanks as the oxygen in the tanks is dry.

**Note the safety factor as the result of the excess flow at high altitudes.

[illegible]

[illegible]

[illegible] and saturation. The oxygen [illegible]

[illegible]

[illegible] per liter of ventilation [illegible]

[illegible]

[illegible]

2. Amounts of Oxygen Required of the Aviator at Rest and at Work

The data given has been presented on the percentage basis of the total respiratory volume. Therefore, it is equally good and valid for the aviator whether he is at rest or at work.

The second stage of the problem, therefore, resolves itself into determining what the ventilation rate is likely to be on the average in an aviator under various conditions of rest and work: (1) the ventilation rate at sitting rest carrying out the usual duties he performs while flying; (2) the ventilation rate when he is actively fighting although sitting; (3) the ventilation rate when he has work to perform which must be continued for some time such as walking about a plane, moving ammunition or attempting to keep warm by shivering; (4) the ventilation rate when he must make some extreme unusual exertion for a short period as in an emergency.

(1) Fortunately there is sufficient data available for the sitting aviator to be able to state that the ventilation rate under sitting conditions in an airplane would vary between 5 and 10 liters per minute (measured at Bar. 37° C Sat.). The upper limit is sufficient even for a large man doing a considerable amount of manipulation of controls although, of course, not having to do what is commonly called "real work."

Therefore, 10 liters per minute (Bar. 37° C Sat.) can be taken as the average maximum volume for the sitting aviator up to and including 35,000 feet; at 40,000 fee one should make an allowance for hyperventilation and consider 15 liters per minte as his average ventilation rate. The total amount of oxygen that he would require would therefore be 10 times that given in either Requirement I or II in Table I up to 35,000 feet; above this level he would require 15 times these amounts. (See Chart VIII)

(2) There is probably little or no data on what an aviator needs when actually fighting. However, during the actual flight it is probable he would be breathing two or possibly three times normal. If fighting cooly and efficiently probably he would not need more than double his respiratory volume. Good fighters could probably be taught not to breathe excessively. In fact, efforts should be made to teach them not to pant or puff because so doing would wash out their carbon dioxide and make them acapnic which is dangerous in itself. However, at present it should be assumed that his ventilation would be 20 liters per minute (Bar. 37° C Sat.)

(3) In the accompanying table, Table II, there is shown the increase in the ventilation rate due to increasing degrees of work. The work was performed in two ways (a) by a man standing and lifting a pail weighing 25 pounds up onto a stool (2½ feet) and (b) by a man sitting and raising a weight of 12 pounds from his knees to way above his head. The work was varied by increasing the number of times per minute the pail or weights were lifted. This type of work simulates the moving of ammunition around in an airplane; however, such work would be interspersed with periods of rest. The volume of the ventilation rate is given in Table II for different degrees of work.

(4) Extreme degrees of muscular work such as would be carried out in an emergency cannot be definitely allowed for in advance. It is quite conceivable that under certain conditions very extreme degrees of work would be carried out. However, this could only be done for a very short period of time and would be beyond the capacity of any oxygen system carried in a plane to maintain adequately for any length of time. However, by a combination constant flow and air-oxygen demand this type of temporary extreme exertion can be easily taken care of.

Table II.

VARIATIONS IN VENTILATION AND OXYGEN CONSUMPTION WITH DIFFERENT AMOUNTS OF WORK

SERIES A

No. times per min.	Approx. foot lbs. of work per min. in raising weight	Ventilation rate L/Min. Bar.37°C Sat.	Oxygen consumption L/Min. STPD
30	1270 - 1350	26 - 37	0.7 - 0.9
26	1080 - 1170	17 - 30	0.6 - 1.0
22	945 - 990	18 - 28	0.7 - 0.8
18	773 - 810	16 - 24	0.6 - 0.7
12	484 - 540	15 - 19	0.6
6	258 - 270	11 - 16	0.4 - 0.5
SERIES B			
20	1250	22 - 44	0.9 - 1.3
18	1063 - 1125	24 - 39	0.7 - 1.2
16	938 - 1000	24 - 38	0.9 - 1.2
14	813 - 875	22 - 33	0.8 - 1.0
10	625	20 - 27	0.7 - 1.0
5	313	17 - 22	0.6 - 1.0

A. the subjects raised the 12 pound weight, while sitting in a chair, from knees to full reach above the head averaging 3.5 feet. Amount of work used in raising arms is not included; nor is the work done while lowering the weight included.

B. The subjects lifted a 25 pound pail from the floor to the top of a bench 2.5 feet high. Amount of work necessary to raise the upper half of body from horizontal to vertical position while lifting the pail is not included; nor is the work done while lowering the weight included.

Five subjects were used, except in the first determination in Series A and the last determination in Series B. Weight of subjects varied from 114 to 184 pounds (51.9 kg. - 84.3 kg.). Height of subjects varied from 5 feet, 7 inches, to 6 feet, 3 inches, (170.5 cm. - 191 cm.).

Mayo Aero Medical Unit
Rochester, Minn.

3. The Oxygen Supply and Distributing System in an Airplane

A. The tests which have been reported at Wright Field indicate that oxygen stored under high pressure (2000 lbs.) is dangerous because if a bullet pierces the tank there is an explosive type of reaction which sends fragments of the tank hurling around the plane. Similar tests on low pressure tanks (around 400 to 500 lbs.) demonstrate that no explosive reaction takes place under these conditions although there may be a sharp hot blaze for a very brief period; the tank fragments are not thrown around however.

B. Another advantage to the low pressure tank is the fact that it can be more easily and economically filled from the outside of the airplane from batteries of large supply tanks at high pressure mounted on air-field trucks. The mechanism for the filling of a low pressure tank is simpler and easier to control than the filling mechanism of a high pressure tank and for that reason the low pressure tank has many practical advantages.

However, regardless of whether a high or low pressure tank is used, a reducing valve should be at or near the tank to reduce the pressure in the piping distribution system to the order of 20 or 30 pounds. The reason for this reduction is that then a comparatively flexible and not too heavy-walled rubber tubing can be used to run from a plug-in type of connector on the side of the plane to the aviator. On the aviator can be placed a small regulator which controls the oxygen flow such as that now being devised by Colonel Fink and Major Kearby. This regulator should be fundamentally of the air-oxygen demand type which preferably has been improved so that it will give in addition a constant flow of 1 to 2 liters per minute that will come on automatically at 30,000 feet and manually at any desired level.

From this regulator conveniently attached to the flying suit a corrugated tubing of the proper length (18 inches) should run up to the mask. The mask should be of the demand type with inspiratory and expiratory valves and microphone. In addition, there should be a small reservoir-rebreathing bag about 4½ inches in diameter and about 6 inches long surrounding and connected to the upper end of the corrugated tube just as it is attached to the mask. The apparatus so arranged has been described in Special Report No. 1 of the Mayo Aero Medical Unit which is herewith attached. This arrangement combines all the advantages of the demand system with the increased safety factors of the constant flow system with practically none of the disadvantages of either system.

The demand mask so modified with the reservoir rebreathing bag attachment will permit the use of one standard type of mask whether the plane be fitted with the constant flow oxygen distribution system or with what is now being introduced as a straight air-oxygen demand. All that would be needed to use either system would be appropriate connectors.

The present straight air-oxygen demand regulator can be altered very easily to give in addition to the demand flow also a constant flow of 1 or 2 liters per minute S.T.P.D. by changing the "emergency" supply.

The pressures inside the mask with the constant flow system are given in Charts 9a, 9b and 9c; at high altitudes there is no negative pressure as there is a large outboard leak. Contrast this with the pressure obtained if the demand system shown in Charts 10a, 10b and 10c where at high altitudes there is marked negative pressure with its attendant dangers, due to leaks. Gagge has shown slight positive pressure adds to altitude tolerance; therefore, the constant flow system is preferred to demand type at high altitudes. The combination of constant flow with the demand system suggested in our Special Report No. 1, herewith attached, is a simple method of obtaining the advantages of both systems.

[illegible]

a. The tests which have been reported [illegible]

b. Another advantage [illegible] political advantages.

However, [illegible]

When this [illegible]

The present [illegible]

The [illegible]

The [illegible]

Appendix I.

From curve 3, Chart III, it may be seen that the desired oxygen percentage in the inspired mixture is equal to the oxygen pressure in the inspired mixture necessary to maintain a tracheal oxygen pressure of 149 mm. Hg (curve 2) divided by the barometric pressure at any altitude. Since the oxygen pressure in the inspired mixture (curve 2) is obtained from the ratio

$$\frac{B}{B - 47} \times 149$$

the desired oxygen percentage (curve 3) is

$$\frac{149}{B - 47} \times 100$$

This percentage may also be expressed in volumes, being equal to the volume of oxygen in the mixture divided by the volume of the mixture. The volume of oxygen present in a mixture of air and oxygen is equal to the volume of oxygen in the air plus the volume of oxygen added. Expressed in symbols, the percentage is

$$\frac{V_{A_{O_2}} + V_{O_2}}{V_T} \times 100$$

where $V_{A_{O_2}}$ is the volume of oxygen in air, V_{O_2} is the volume of oxygen added, and V_T is the total volume of the mixture. The volume of oxygen, however, in any volume of air is equal to the volume of air multiplied by the percentage of oxygen in the air (0.209 for atmospheric air). (Of course both volumes must be measured under identical conditions.)

Substituting for the volume of oxygen in air, the percentage of oxygen in the mixture becomes

$$\frac{0.209 \times V_A + V_{O_2}}{V_T} \times 100$$

where V_A is the volume of air in the mixture. Since

$$V_T = V_A + V_{O_2}$$

then

$$V_A = V_T - V_{O_2}$$

Substituting for V_A, the percentage of oxygen becomes

$$\frac{0.209\ (V_T - V_{O_2}) + V_{O_2}}{V_T} \times 100$$

Equating this percentage to the desired percentage of oxygen at any altitude, the following equation is obtained:

$$\frac{0.209\ (V_T - V_{O_2}) + V_{O_2}}{V_T} = \frac{149}{B - 47}$$

Solving for the volume of oxygen to be added,

$$V_{O_2} = \frac{149 - 0.209\ (B - 47)}{0.791\ (B - 47)} \times V_T \qquad \text{(I)}$$

Assuming V_T is equal to a ventilation rate of 1 liter per minute (Bar. 37°C Sat.), the volume of oxygen added (Bar. 37° C Sat.) per liter of ventilation becomes

$$V_{O_2}\ (\text{Bar. } 37^\circ \text{ C Sat.}) = \frac{188.369}{B - 47} - 0.264 \qquad \text{(II)}$$

The data from equation II is plotted as curve 4.

If the volume of oxygen added is desired under S.T.P.D. conditions, the volume of oxygen added (Bar. 37° C Sat.) may be reduced to S.T.P.D. or V_T may be substituted into equation I under S.T.P.D. conditions instead of Bar. 37° C Sat. A ventilation rate of 1 liter per minute (Bar. 37° C Sat.) becomes under S.T.P.D. conditions

$$V_T(\text{S.T.P.D.}) = 1 \times \frac{B - 47}{760} \times \frac{273}{273 + 37}$$

Substituting V_T (S.T.P.D.) = in equation I,

$$V_{O_2}\ (\text{S.T.P.D.}) = \frac{149 - 0.209\ (B - 47)}{0.791\ (B - 47)} \times \frac{B - 47}{760} \times \frac{273}{273 + 37}$$

$$V_{O_2}\ (\text{S.T.P.D.}) = 0.2183 - 0.0003061\ (B - 47) \qquad \text{(III)}$$

The data from equation III is plotted as curve 5.

Appendix II - Report #3

Amplification of steps cited in Appendix I.

(a) Solving equation for V_{o2}

$$\frac{0.209\ (V_t - V_{o2}) + V_{o2}}{V_t} = \frac{149}{B - 47}$$

$$\frac{0.209\ V_t - 0.209\ V_{o2} + V_{o2}}{V_t} = \frac{149}{B - 47}$$

$$\frac{0.209\ V_t + 0.791\ V_{o2}}{V_t} = \frac{149}{B - 47}$$

$$\frac{0.209\ \cancel{V_t}}{\cancel{V_t}} + \frac{0.791\ V_{o2}}{V_t} = \frac{149}{B - 47}$$

$$0.209 + \frac{0.791\ V_{o2}}{V_t} = \frac{149}{B - 47}$$

$$\frac{0.791\ V_{o2}}{V_t} = \frac{149}{B - 47} - 0.209$$

$$\frac{0.791\ V_{o2} \times \cancel{V_t}}{\cancel{V_t}} = \left[\frac{149}{B - 47} - 0.209\right] \times V_t$$

$$0.791\ V_{o2} = \left[\frac{149}{B - 47} - 0.209\right] \times V_t$$

$$0.791\ V_{o2} = \left[\frac{149}{B - 47} - \frac{0.209\ (B - 47)}{B - 47}\right] \times V_t$$

$$V_{o2} = \frac{149 - 0.209\ (B - 47)}{0.791\ (B - 47)} \times V_t$$

(b) Solving equation for V_{o2} (Bar. 37° C Sat.) where $V_t = 1$.

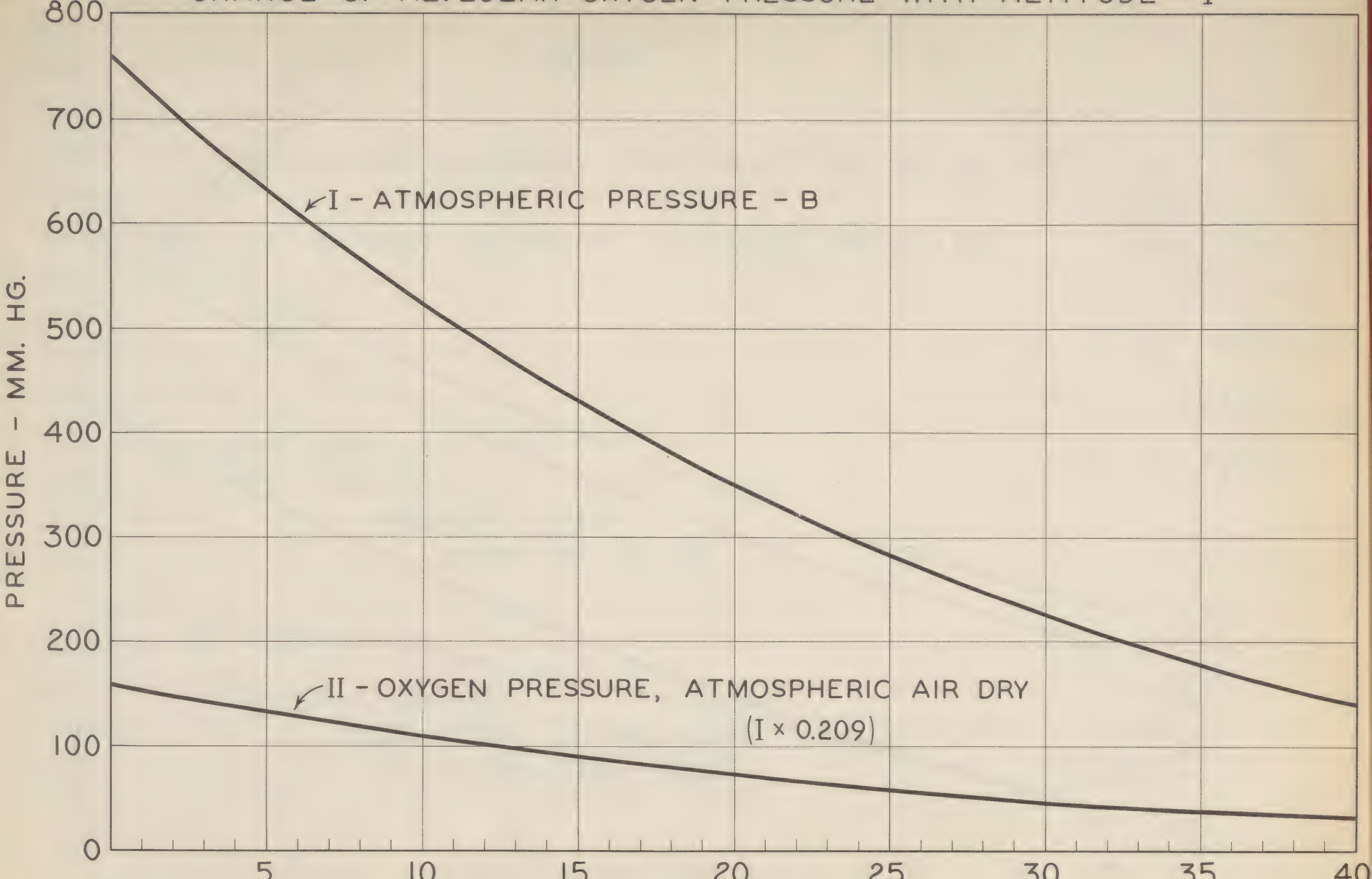
$$V_{o2}\ (\text{Bar. } 37^\circ \text{ C Sat.}) = \frac{149 - 0.209\ (B - 47)}{0.791\ (B - 47)} \times V_t$$

$$V_{o2}\ (\text{Bar. } 37^\circ \text{ C Sat.}) = \left(\frac{149}{0.791\ (B - 47)} - \frac{0.209\ \cancel{(B - 47)}}{0.791\ \cancel{(B - 47)}}\right) \times 1$$

$$V_{o2}\ (\text{Bar. } 37^\circ \text{ C Sat.}) = \frac{149}{0.791\ (B - 47)} - \frac{.209}{.791}$$

$$V_{o2}\ (\text{Bar. } 37^\circ \text{ C Sat.}) = \frac{188.369}{B - 47} - .264$$

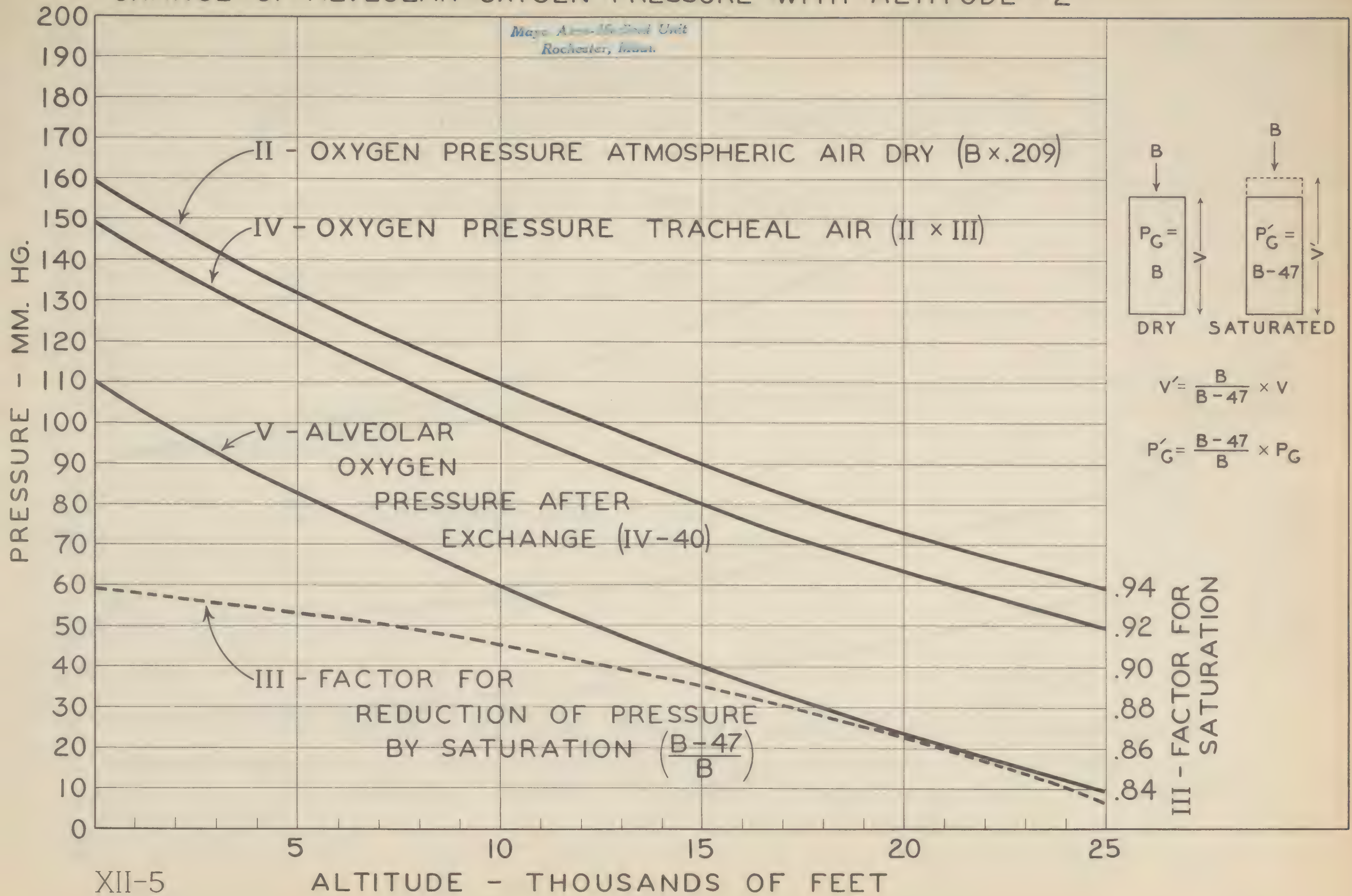
CHANGE OF ALVEOLAR OXYGEN PRESSURE WITH ALTITUDE - 1



XII-4

May 1942 J. Berkson and W.M.Boothby

CHANGE OF ALVEOLAR OXYGEN PRESSURE WITH ALTITUDE - 2



XII-5

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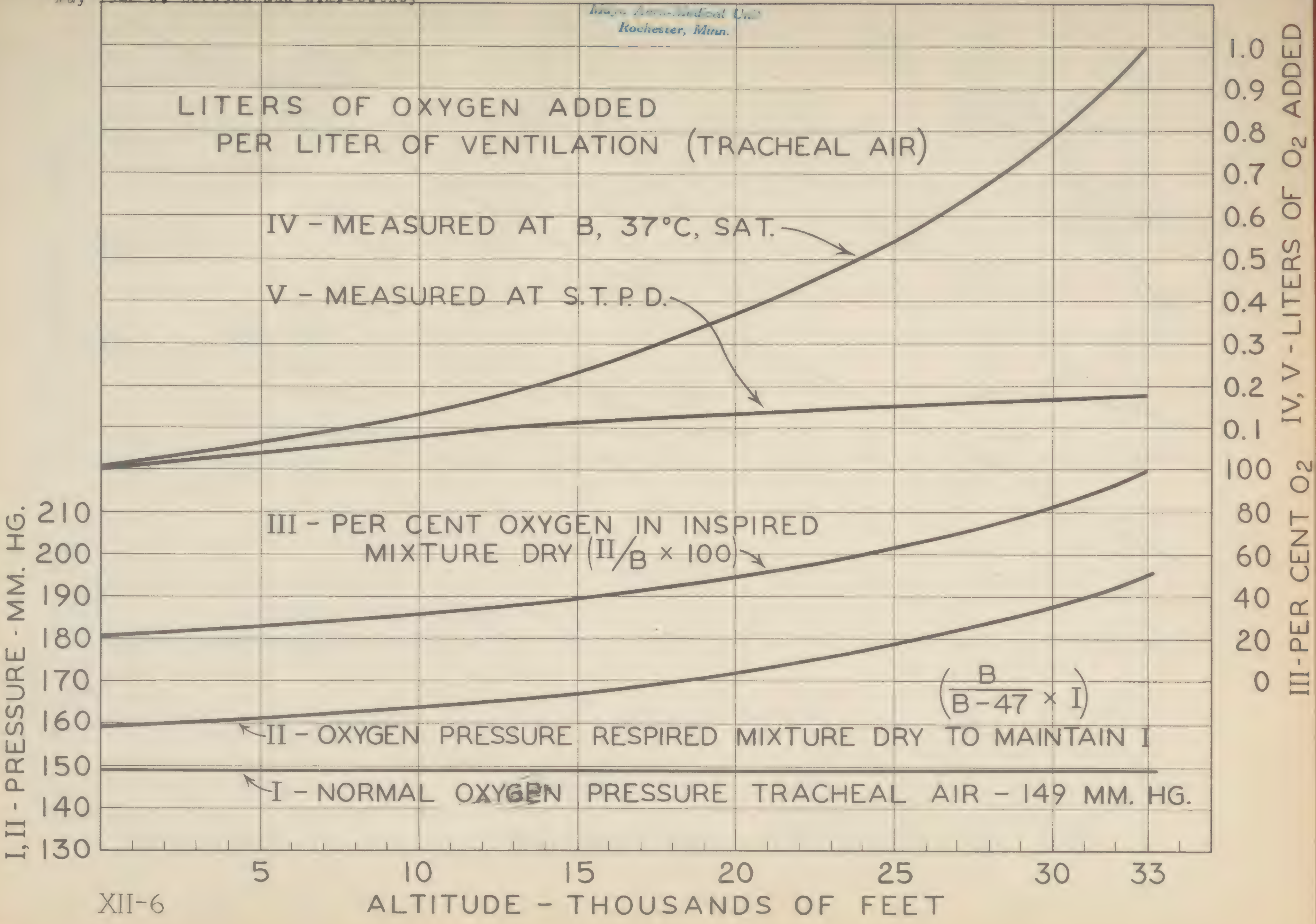
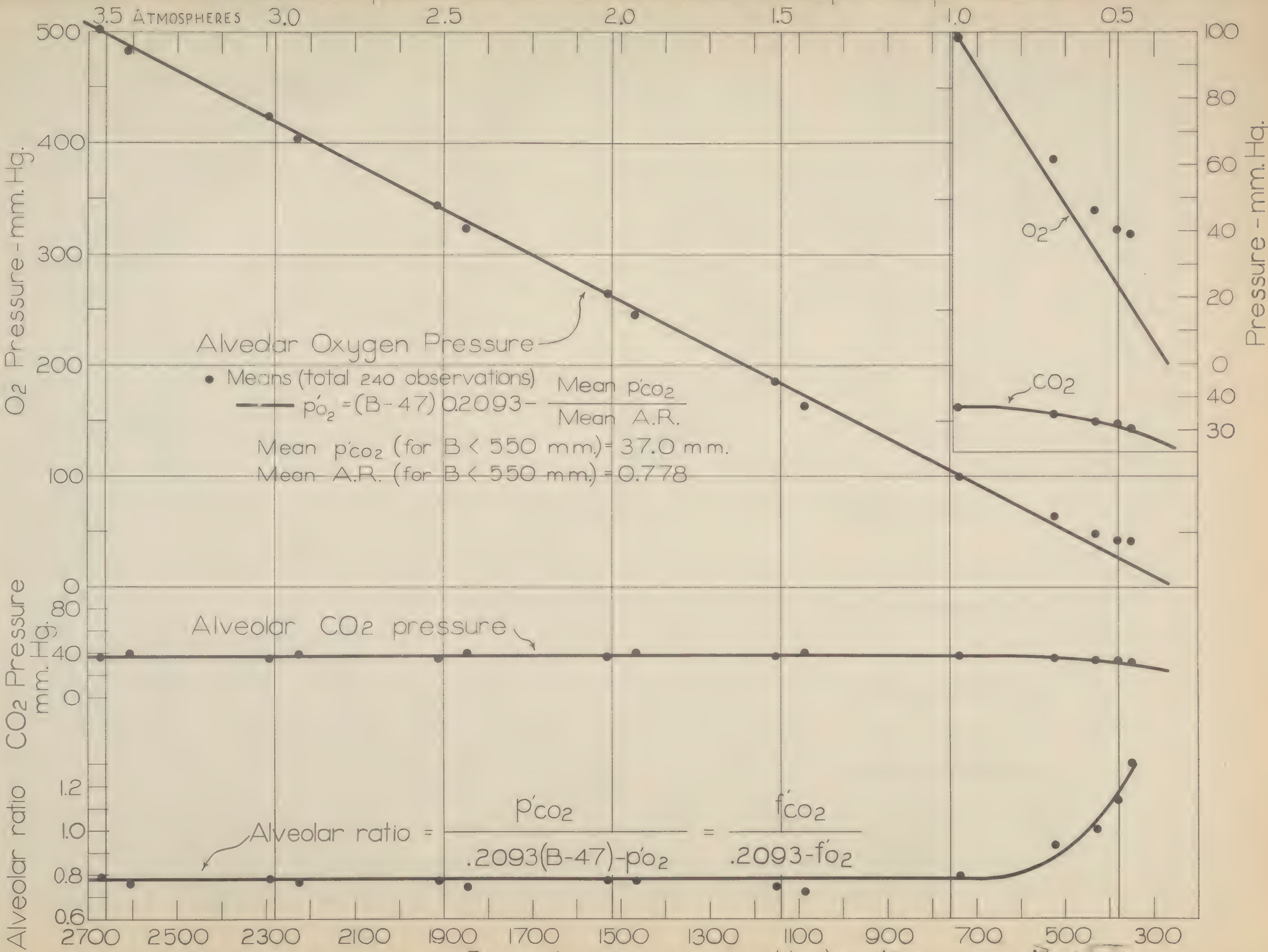


XII-6

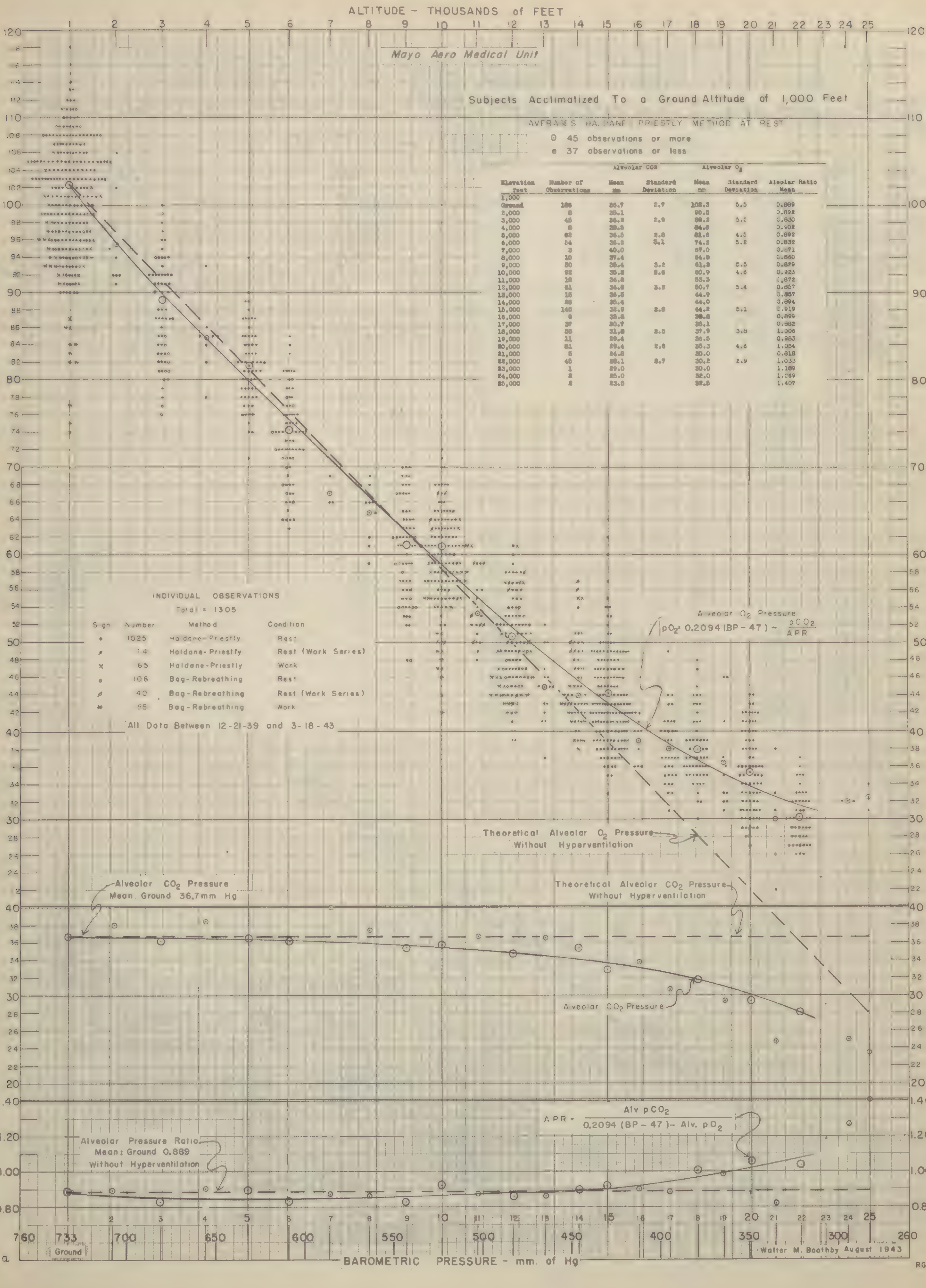
Alveolar pressures for various total atmospheric pressures



XII 7-a corrected

May 1942 W. M. Boothby

Alveolar O_2 and CO_2 Pressures and Alveolar Ratio at Various Altitudes while Breathing Air



		Alveolar CO2		Alveolar O_2		
Elevation feet	Number of Observations	Mean mm	Standard Deviation	Mean mm	Standard Deviation	Aleolar Ratio Mean
1,000 Ground	186	36.7	2.7	103.3	5.5	0.889
2,000	8	38.1		96.5		0.898
3,000	45	36.2	2.9	89.2	5.2	0.830
4,000	6	38.5		84.6		0.902
5,000	62	36.5	2.8	81.6	4.5	0.892
6,000	54	36.2	3.1	74.2	5.2	0.832
7,000	3	40.0		67.0		0.871
8,000	10	37.4		64.8		0.860
9,000	50	35.4	3.2	61.2	5.5	0.879
10,000	92	35.8	2.6	60.9	4.6	0.925
11,000	12	36.8		55.3		0.872
12,000	61	34.8	3.2	50.7	5.4	0.857
13,000	15	36.5		44.9		0.857
14,000	26	35.4		44.0		0.894
15,000	145	32.9	2.8	44.2	5.1	0.919
16,000	9	33.8		38.6		0.899
17,000	37	30.7		38.1		0.882
18,000	55	31.8	2.5	37.9	3.8	1.006
19,000	11	29.4		36.5		0.983
20,000	81	29.4	2.6	35.3	4.6	1.054
21,000	5	24.8		30.0		0.818
22,000	45	28.1	2.7	30.2	2.9	1.033
23,000	1	29.0		30.0		1.189
24,000	2	25.0		32.0		1.269
25,000	2	23.5		32.5		1.407

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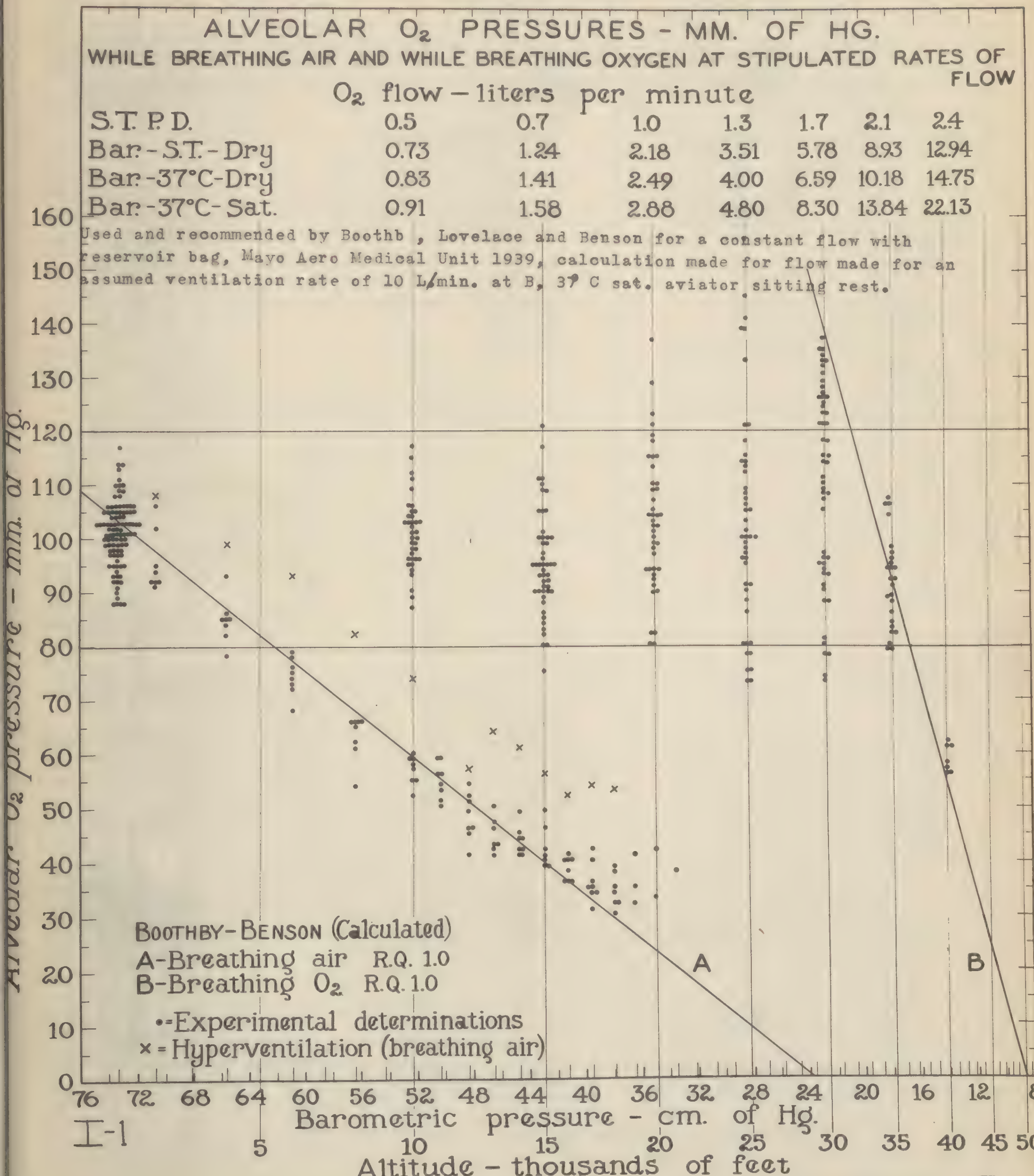
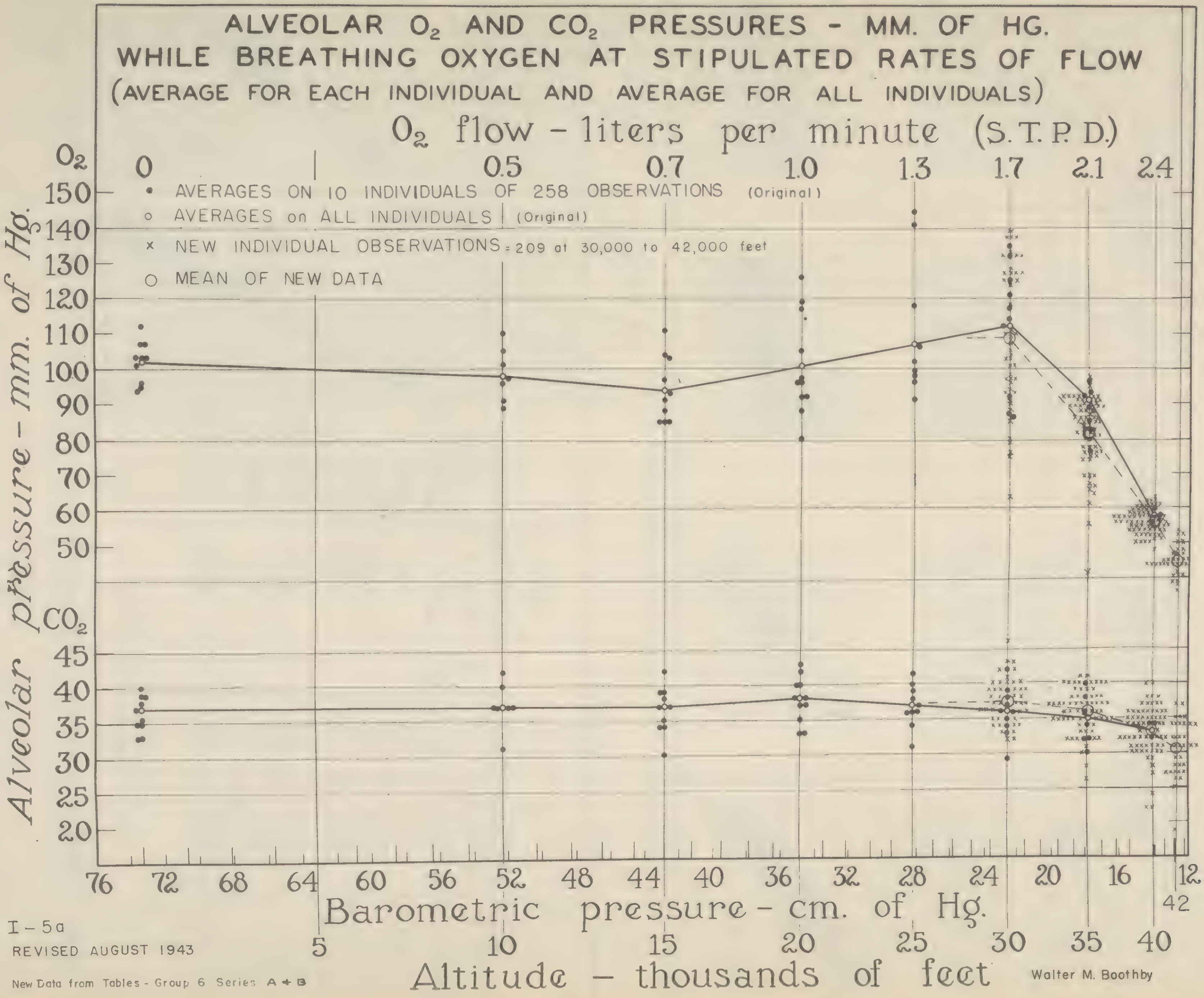
RGK

Subject: High altitude effect on the human body
Published: J. Aeronaut. Sc. 7: 465, Sept. 1940



Wm. Boothby, W. R. Lovelace II, A. O. Benson Jr.
Sept. 1940



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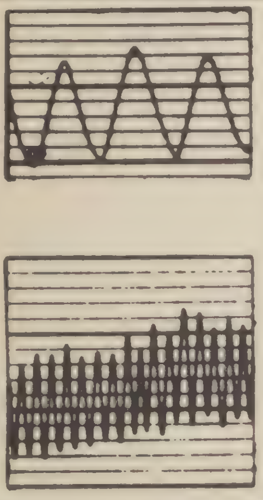
REVISED AUGUST 1943
New Data from Tables - Group 6 Series A + B

Walter M. Boothby

MAYO AERO MEDICAL UNIT

OXYGEN CONSUMPTION AND VENTILATION RATE PER MINUTE AT VARIOUS ALTITUDES WHILE BREATHING OXYGEN

GROUND
BAR.: 733



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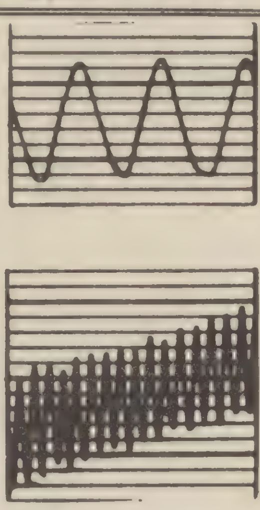
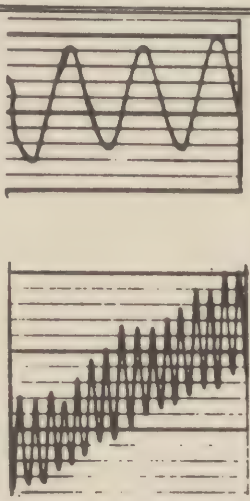
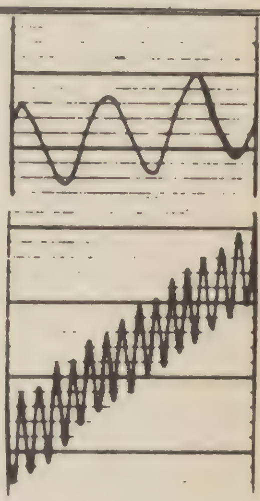


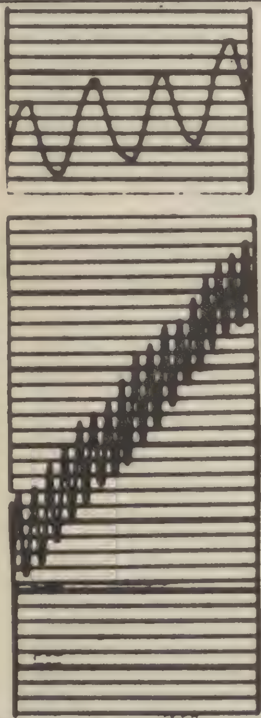
20,000 FT.
BAR.: 349



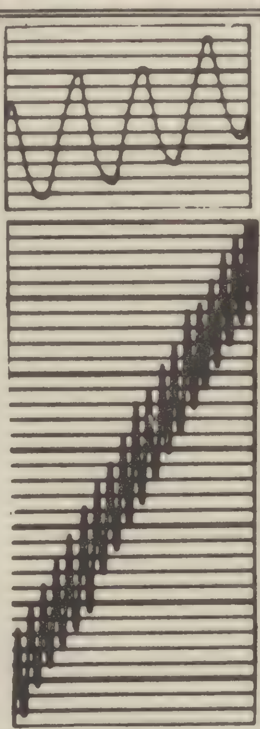
30,000 FT.
BAR.: 226



35,000 FT.
BAR.: 179



40,000 FT.
BAR.: 141



SUBJECT O.O.B. (1-29-40) at sitting rest

ALTI-TUDE IN FT.	O_2 CON-SUMPTION S.T.P.D. c.c.	Sitting Rest VENTILATION RATE S.T.P.D. Liters	B-37°-D. Liters	B-37°-S Liters
1,000	244	6.79	7.93	8.47
10,000	264	5.37	8.86	9.74
20,000	256	3.01	7.45	8.61
30,000	255	1.68	6.42	8.10
35,000	259	1.50	7.23	9.81
40,000	273	1.39	8.51	12.77

XIV-1

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